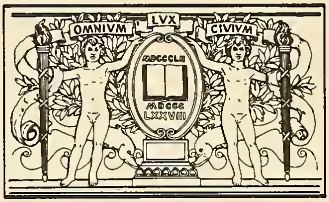
A
M3/B16
TP
84/3 ✓

BOSTON PUBLIC LIBRARY
3 9999 06588 456 9



BOSTON
PUBLIC
LIBRARY

Digitized by the Internet Archive
in 2011 with funding from
Boston Public Library

http://www.archive.org/details/efficientoperati00bost

BRA 250
BRA-0201
Δ
/B16
P
/3

BOSTON PUBLIC LIBRARY
GOVERNMENT DOCUMENTS DEPARTMENT
RECEIVED
DEC 17 1985

EFFICIENT OPERATION OF OFF-STREET PARKING IN BOSTON

Prepared by

BOSTON REDEVELOPMENT AUTHORITY

For

TRAFFIC & PARKING DEPARTMENT

CITY OF BOSTON

RAYMOND L. FLYNN, MAYOR

Sponsored by

THE METROPOLITAN AREA PLANNING COUNCIL
and partially funded by

URBAN MASS TRANSPORTATION ADMINISTRATION
ENVIRONMENTAL PROTECTION AGENCY

Project #MA-19-0013

JANUARY, 1984

Efficient Operation of
Off-Street Parking
in Boston

Ellen Collins

Boston Redevelopment Authority
Transportation Planning Department

ROBERT J. RYAN, DIRECTOR

January, 1984

For the City of Boston Traffic & Parking Department
ROBERT F. DRUMMOND, ACTING COMMISSIONER

RAYMOND L. FLYNN, MAYOR

Sponsored by

The Metropolitan Area Planning Council

Project # MA-19-0013

Table of Contents

Page

EXECUTIVE SUMMARY 3

I. Introduction 5

II. Background 6

- A. Air Quality Standards for the Boston Region 6
- B. Parking and Air Quality 7

III. Design and Operation of Parking Facilities 10

- A. Current City Regulations Regarding Parking Facilities 10
- B. Design Guidelines from Parking Literature 13
- C. Summary 16

IV. Characteristics of Parking Facilities in Boston Proper 17

- A. Types 17
- B. Markets Served and Locations 18
- C. Traffic Characteristics of Downtown Streets 19

V. Factors Affecting the Efficiency of Parking Facilities 21

- A. Introduction 21
- B. Entering Delay Factors 22
- C. Exiting Delay Factors 25
- D. Outside Facility Delays 30
- E. Cruising for Parking 33
- F. Summary 35

VI. Recommendations for Improvements 37

- A. Air Quality Impacts of Specific Operating Improvements 37
- B. Case Study of Operating Improvements at Winthrop Square 42
- C. Guidelines and Standards for Future Construction 50
- D. Summary 50

Footnotes 53

Appendix 54

EXECUTIVE SUMMARY

The Boston region does not yet comply with Federal air quality standards; so strategies which will produce further improvements in air quality are being sought. Automobile congestion is one cause of poor air quality, since cars idling and traveling at low speeds produce "excessive" emissions. Therefore, actions which alleviate congestion will also help to improve local air quality.

In Boston Proper, congestion frequently results from the operation of parking facilities. Peak and off-peak operations of several Boston Proper lots and garages were observed, with particular attention paid to those facilities which produced extreme congestion. Four problems areas involving parking facility operations are:

- delays to entering vehicles
- delays to exiting vehicles
- delays to general traffic (external to parking facility)
- excessive travel ("cruising" for parking)

Characteristics of parking facility operation and layout which contribute to these four congestion-causing conditions were specified, and quantified where possible.

The following measures to improve air quality through modifications to existing facilities are grouped below according to their effects:

1. Increasing Speeds of Entering/Exiting Cars Through:
    - increasing the number of open gates
    - reducing pedestrian/vehicle conflict
    - internal signage
2. Reducing Idling Through:
    - speeding up transaction at gate
    - encouraging a simple fee structure
    - adequate reservoir
3. Reducing On-Street Delays Through:
    - traffic regulation
    - traffic enforcement

In order to assess the effectiveness of these recommendations, one garage in Downtown Boston was chosen to be the subject of a case study. Two of the above recommendations-increasing the number of open gates, and prohibiting standing through traffic regulation and enforcement-were proposed as modifications to the existing operation. Existing garage-generated carbon monoxide was modelled, in addition to the changes expected if the recommendations were implemented. The projected peak-hour decreases in CO levels were quite significant, and at one location, it demonstrated that CO could be reduced as much as from 11.5 to 1.0 parts per million. It is estimated that for most parking facilities that cause excessive congestion, an average of 3-4 parts per million decrease in CO could occur through adoption of these recommendations.

Implementation of these low cost measures by private operators would most likely require an incentive. It is proposed that there be established a "standard of operation" which would provide that every parking facility must operate in a fashion which does not impose excessive costs upon others (such as congestion) and would require enforcement by the Traffic & Parking Department or the Air Pollution Control Commission. Legislation on the state or city level may be required in order to set up a standard and empower an authority to enforce it.

In conjunction with a proposed operating standard, or independently, some guidelines to be used during design review of future facility construction are recommended. These recommendations derive from the physical deficiencies identified through garage observations, and would require major modifications to existing facilities. Therefore, standards and guidelines for:

- location of entrances and exits
- number of gates
- reservoirs
- internal layout and operation

are recommended for incorporation into the formal and informal review process. Design standards such as these would help to reduce CO levels in the vicinity of parking facilities over the long term.

EFFICIENT OPERATION OF OFF-STREET PARKING IN BOSTON

I. INTRODUCTION

Of the 100,000 or so vehicles which are destined to Downtown Boston each weekday, almost every one is "parked" for some amount of time. These 100,000 vehicles move into and out of over 55,000 off-street parking spaces and approximately 10,000 legal on-street (curbside) spaces. Since a large proportion of this parking activity occurs during the morning and afternoon peak periods (7-9 A.M.) and (4-6 P.M.), it is not surprising that congestion is frequently associated with parking, and in particular with the operation of off-street parking.

Congestion and queuing of vehicles, as a result of parking lot and garage operation, is the subject of this study. Although at first glance it might appear that parking problems are of limited impact, a wider constituency than just parking facility patrons can benefit from efficient parking operations. Congestion and queuing are responsible, in part, for deterioration in local air quality, the waste of gasoline, and the useless expenditure of motorists' time. Furthermore, traffic congestion and queues delay the progress of emergency vehicles, as well as that of buses carrying many more passengers than automobiles. Pedestrians, too, are inconvenienced by cars blocking crosswalks and endangered by crossing the street with reduced sight lines.

One impact of parking-related congestion which has aroused concern is the degradation of the quality of the air around some facilities. Responding to these conditions, the Environmental Protection Agency (EPA) through the supervision of the Metropolitan Area Planning Council funded this study to examine the operation of parking facilities in Boston from an air quality perspective and to recommend actions to alleviate congestion and the concomitant deterioration of the air.

The first task in this Study was to observe the operation of both parking lots and garages in Boston Proper (the area within Massachusetts Avenue) and to identify facilities that seemed to generate congestion. More detailed examination of several facilities was required in order to determine the differences between those which operated efficiently and those that did not. Through many hours of peak and off-peak observations of mechanical and ramp garages and valet and self-park lots, several factors contributing to poor operation became evident. To reinforce our observations, quantitative measures of processing capacities were constructed through both field study and reference to the parking literature, resulting in identification of the salient characteristics of design and operation contributing to delay and excessive vehicular emissions.

Two distinct categories of recommendations arose from these findings. One is concerned with the adoption of standards and guidelines for future parking facility design and operation, and the other proposes a "standard of operation" which would require operating modifications to existing facilities which do not operate in an efficient manner.

It is hoped that this report has relevance not only to Boston, but to other cities which face parking-related congestion and queuing.

II. BACKGROUND

A. Air Quality Standards for the Boston Region

The Federal Clean Air Act of 1967 and subsequent legislation established regional air quality standards in response to the deterioration of the nation's air. Concern about air pollution stemmed from documented respiratory problems which were caused or exacerbated by air-borne pollutants. Consequently, air quality standards were developed for five major pollutants; however, only those which relate to automotive emissions will be discussed here: carbon monoxide, hydrocarbons, and nitrogen oxide.

Carbon monoxide (CO) is produced by the incomplete burning of gasoline in internal combustion engines. It is estimated that automobiles are the source of 90% of the CO in the Boston region.[1] At low concentrations, CO can cause headaches and impaired perceptions; when very concentrated, can result in death.[2]

Federal standards have been established for an 8-hour average level of CO of 9 parts per million (ppm), and a one-hour standard of 35 ppm. An air quality monitoring station is located just outside of Boston Proper at Kenmore Square. The one-hour standard for CO has not been exceeded in recent years at this station, but the 8-hour average was exceeded one time in 1980. However, at the Callahan Tunnel in East Boston, the 8-hour standard was exceeded on 10 days during the first half of 1980, when monitoring was in progress. Consequently the region is not yet in compliance with the CO standards.

Photochemical oxidants, known as smog or ozone, are produced by a reaction of sunlight with hydrocarbons and nitrogen oxides, both of which are emitted by automobiles. Ozone can cause respiratory ailments and damage to vegetation. The one-hour standard for ozone is 120 parts per billion, and the maximum level recorded in 1980 at the monitoring station in East Boston was 59 ppb. However, measurements exceeding the standard have been recorded in suburban locations, and thus the Metropolitan area is not in compliance with ozone standards.

This does not lead to the conclusion that there is no ozone problem in the City of Boston, however. Since the formation of ozone requires time for the reaction between HC and NO_x and sunlight, the wind may carry these pollutants from Boston Proper to nearby locations by which time they have converted to ozone. Thus, it can be seen that pollution is a regional problem, and the region, through the Metropolitan Area Planning Council and the Commonwealth, are searching for strategies to reduce vehicular emissions.

The current deadline for achievement of the ambient air quality standards is December, 1987. Towards this goal, the Commonwealth submitted a State Implementation Plan (SIP) in 1982 which specifies the measures which are to be implemented in order to comply with the standards.

It is anticipated that the CO standards will be met by 1987 in large part due to the Federal regulations regarding emissions standards for new automobiles. Projections made in 1978 estimate that the region may not be in compliance with the ozone standard by the deadline. Therefore, strategies which will cause a further decline in emissions are being sought.

Basically there are two methods by which to control vehicular emissions. One type is through the manufacturing emission Control Standards of the Federal Government and the Inspection and Maintenance (I & M) of car exhaust systems, an annual check required by the Commonwealth. The second is to control the use of vehicles, since the amount of emissions exhausted is roughly proportional to the amount of travel.

In order to reduce the amount of automotive travel, many of the strategies developed in the SIP provide incentives to use public transportation and carpool. Another group of strategies aim to restrict automobile usage through programs such as the Parking Freeze. A third category is devoted to reducing the emissions of automobiles already on the road through traffic and operational improvements. The parking strategies discussed in this report to mitigate air pollution fall under this latter category.

B. Parking and Air Quality

The role that parking plays in efforts to improve air quality is a fundamental one. Most personal automobile travel could not occur unless there existed a place to temporarily store vehicles while automobile passengers participate in the activities which are the purpose of the trip. This simple relationship leads to the assumption that by altering the amount of vehicle storage available, automobile usage and vehicle miles travelled (VMT) can be influenced. This is the underlying rationale behind two current parking programs administered by the City of Boston - the Parking Freeze and Resident Sticker Parking.

This report, however, looks at a different aspect of the relationship between parking and air quality - the congestion and queuing which frequently occurs as a result of parking, particularly in the morning peak period. Low travel speeds, idling, braking and acceleration add disproportionately more to pollution levels than does travel under free flow conditions; and if the conditions which cause this could be changed, a decrease in localized carbon monoxide levels could result.

Specific parking facility characteristics which contribute to congestion and queuing will be discussed later in this report. Generally speaking, however, when many slow-moving vehicles converge on a small area, typical of off-street parking facilities, emissions are concentrated rather than dispersed as in curbside parking. Therefore, increasing the speeds of cars entering and exiting parking facilities, and minimizing idling outside of parking facilities are two general techniques which would improve local air quality. A third method is to reduce conflicts between through traffic and vehicles destined to parking facilities.

Conflicts between cars entering parking facilities and general traffic are exacerbated because the peak times of parking arrivals and departures generally parallel those of general traffic. Since Boston's streets are generally at capacity during peak hours, and alternate routings are limited, the system does not have the capacity to adjust well to congestion. Consequently, air quality deterioration due to parking facilities can "felt" even several blocks distant from the source of the problem.

To summarize, three basic ways of improving air quality will be discussed:

- increasing speeds of cars entering and exiting facilities;
- minimizing idling time;
- reducing on-street congestion and conflicts between general traffic and vehicles destined to parking facilities.

1. Increasing Speeds of Entering Cars

Automotive emissions are a function of vehicular speed. A vehicle travelling at a constant speed of 5 miles per hour emits 232 grams of CO per vehicle mile travelled at 20°F (1983) whereas a car travelling at 15 miles per hour under similar circumstances has CO emissions of 87. Therefore, if an approach to an entrance gate is 150 feet long and entering cars are travelling at a constant rate of 15 mph, 2.47 grams of CO would be emitted by each car over that distance, and 6.59 at 5 miles per hour. Although small on an individual basis, this illustrates the magnitude of improvements that could be brought about by changes in approach speed. Figure 1 depicts the relationship between constant travel speeds and emissions.

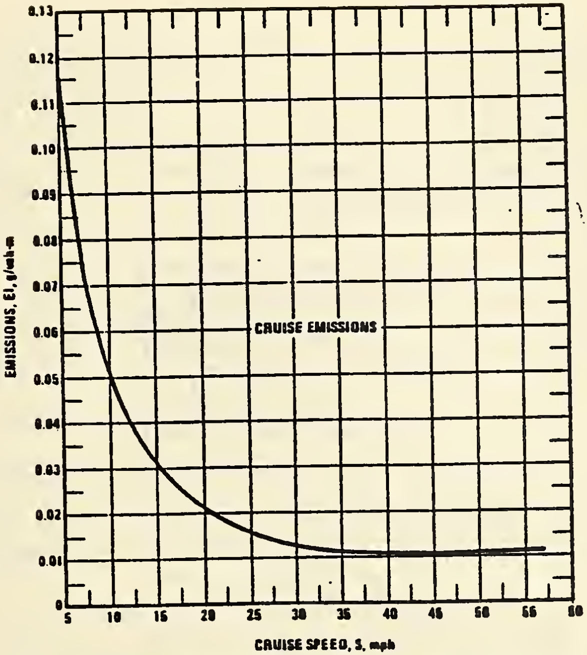
Approach speed is highly influenced by the volume/capacity ratio. The closer the volume to capacity ratio is to one-in other words, as the demand for the facility approaches its design capacity-travel speeds will decline. Figure 2 illustrates how the volume of vehicles on a link (or the volume/capacity ratio) affects cruise speed. The dotted line on the bottom, labeled "Level F", delineates the combinations of cruise speeds and volumes that would constitute level of service F, or highly congested conditions.

As the number of vehicle arrivals increase within a given time period, and particularly as the volume/capacity nears the 80% range, what occurs is not a uniform decrease in cruise speeds, but uneven flow characterized by stops and starts. During the acceleration and deceleration that accompanies stops and starts, emissions in excess for those at a constant cruise speed are produced. Note in Figure 3 how these excess emissions are proportionally very great when the cruise speed is low, which is the typical condition at parking facilities.

This combination of excess emissions produced as a result of low travel speeds and stop and go conditions can be mitigated by strategies which increase travel speeds.

2. Minimization of Idling

Idling may perhaps be the largest contributory factor to excessive emissions. 11.5 grams of CO are emitted, per minute, by an average idling automobile. Furthermore, idling emissions are unproductive emissions since these are produced in addition to any travel emissions.



Emissions as a function of speed for a 1977 base year, 0% cold starts, 75°F, low altitude, non-California, and 100% $\overline{\text{LDV}}$.

FIGURE 1*

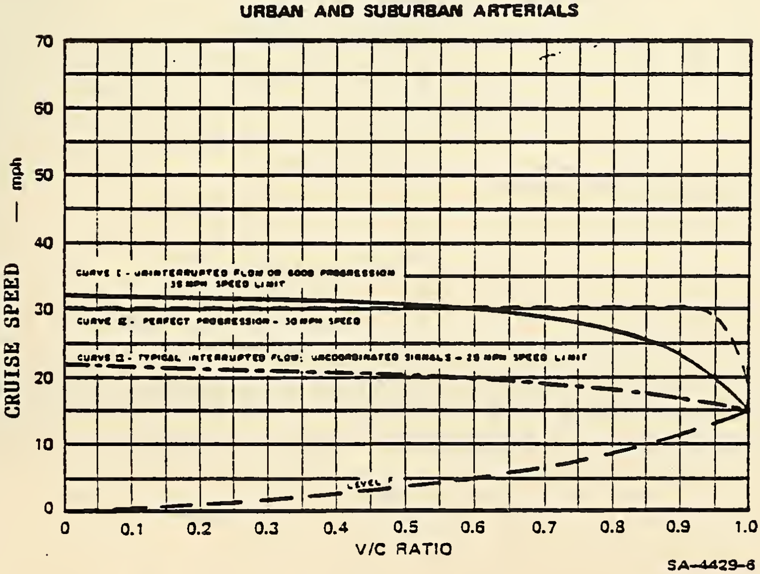
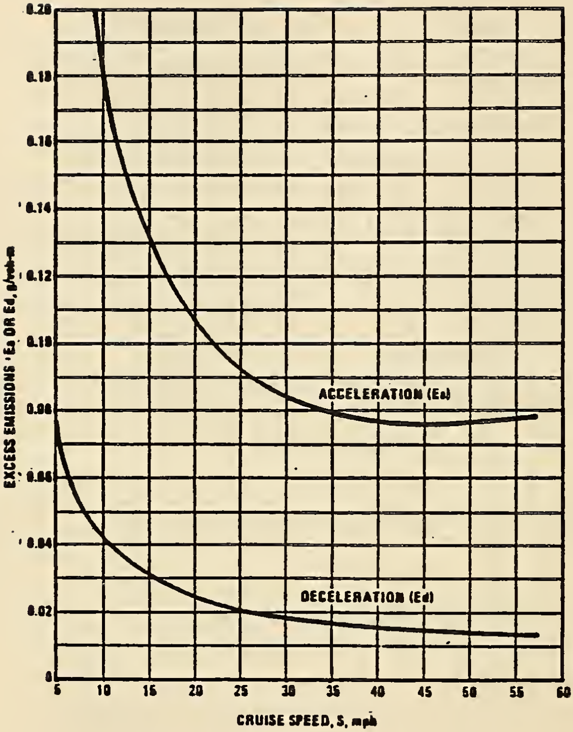


FIGURE 2*

TYPICAL RELATIONSHIPS BETWEEN V/C RATIO AND AVERAGE OVERALL TRAVEL SPEED, IN ONE DIRECTION OF TRAVEL, ON URBAN AND SUBURBAN ARTERIAL STREETS



Excess emissions due to acceleration to or deceleration from cruise speed (1977 base year).

FIGURE 3*

---

*Figures 1, 2 and 3 from "EPA Guidelines for Air Quality Maintenance Planning and Analysis Volume 9 (Revised): Evaluating Indirect Sources, Second Printing, EPA - 450/4-78-001, Research Triangle Park, NC, September 1978."

For example, if a car is sitting in a queue, idling emissions are added to the emissions exhausted by travelling at slow speeds, resulting in truly unnecessary emissions. Naturally, an isolated car or two does not produce these above described conditions - so when idling occurs, it generally indicates a large number of individual vehicles are exhausting emissions in concentration. Exceptions to this are seen, particularly during midday, when just one or two cars idle at a gate waiting for a space to open.

This should give some perspective on how idling causes poor local air quality, particularly when we will see that idling in front of parking facilities can be measured in half-hours, not seconds. Strategies for reducing or eliminating idling then should be emphasized as key for improving air quality in the vicinity of a facility where this occurs.

3. Reduction in On-Street Traffic Delays

This category of air quality improvements contains elements of both increasing travel speeds and minimizing idling, but the impact is on general traffic, those cars not destined to the parking facility in question. The relationship between emissions and speeds holds as described above.

The intent of this study is to measure the efficiency of various types of parking facilities with different characteristics, and attempt to measure and isolate the characteristics which impede the smooth flow of vehicles through a parking facility. By identifying those operational and design characteristics which can be modified, and their contribution to congestion and queuing, estimates of possible improvements and their associated air quality benefits can be made.

III. DESIGN AND OPERATION OF PARKING FACILITIES

Good design and efficient operation of parking facilities is of interest for several reasons. From the operators' point of view, land (and structure) is quite costly, and good design can maximize the number of parking spaces that can be accommodated on a given parcel. Good design and operation can also minimize congestion and delay in and around a facility; such delays can be seen as additional costs to patrons, and result in a loss of business.

The City, also, is concerned with efficient operation and design of parking facilities. Their interest, however, differs from that of the parking operator. The quality of the overall flow of traffic and the mitigation of congestion is a constant concern of the Traffic & Parking Department. Since parking facilities rank among the largest generators of traffic, their integration and coordination with the streets of the City are a matter of concern. Planning issues centered around parking in Downtown Boston acknowledge the delicate balance of providing sufficient parking in order to support activities, yet ensuring that the Downtown is not strangled by traffic. Nor is it desirable for the Downtown to be "dotted" with parking lots which tend to appear on formerly vacant parcels, crowding out other land uses preferred by the City and frequently presenting a haphazard and unattractive appearance.

Regulation of parking facility operation and design is carried out by several City authorities. The zoning code contains parking standards and is supplemented by and superceded within Boston Proper by the Air Pollution Control Commission's (APCC) criteria. The City Traffic & Parking Department has a set of requirements which must be met prior to their issuance of an open-air parking lot license. The City Building Department adheres to the Commonwealth's State Building Code regarding standards for parking structures.

The Public Improvement Commission (PIC), whose members include the Commissioner of the Public Works Department, Traffic & Parking, Water & Sewer Commission, Building Department and Real Property, must approve any physical changes within, or alteration of, the public rights-of-way. More minor modifications to the street such as curb cuts must be approved by the Chief Engineer of the Public Works Department, with concurrence of the Traffic and Parking Department which thus gives city staff the authority to review a proposed parking facility.

A. Current City Regulations Regarding Parking Facilities

1. Review Process

Unwritten, as well as written standards are exercised through the various reviews in the bureaucratic process. Engineering plans for a proposed parking lot or garage must be submitted to the Traffic & Parking Department and the Public Works Department for approval if a curb cut is needed, which is usually the case. At this time, these agencies may not approve the proposal if it is felt that an aspect of the lot's operation or layout is unsafe, or is not in the City's best interest.

If the lot or garage is located within Boston Proper, the Air Pollution Control Commission (APCC) must approve a request for commercial spaces, or exempts the petitioner from the freeze if the facility is not available to the general public. The Commissioners often can persuade a facility owner to adopt recommendations prior to the issuance of a permit.

Zoning Board of Appeal approval is required for a parking facility which is located in a district where parking is considered a conditional use. This review is required for all facilities which fall under the jurisdiction of the APCC, as well as peripheral areas of the core city.

The Building Department will not issue a construction permit for a garage unless the aforementioned approvals have been obtained.

Finally, a license for parking lots only must be obtained through the Traffic and Parking Department. Again, unless the appropriate permits and approvals have been acquired, a license will not be issued. The current fee for licensing is $24 per year per space, and an additional fee of $1 per year per space is levied, ranging from a minimum of $25, to a maximum of $200. The Fire Department imposes a flat fee per parking facility of $50.

2. Zoning Codes

Prior to the Boston Transportation Planning Review (BTPR), zoning for parking was predicated on requiring a certain number of spaces per square foot of structure, varying by district and by land area. This was to ensure that there would be sufficient parking to support development, and that there would not be spillover to on-street parking. Included in the code were incentives to exceed the minimum required parking, which then permitted an increase in the floor area.

The Zoning Code, revised in 1973, eliminated the parking requirement for all but residential uses, and introduced the concept of a Restricted Parking District, in which non-residential parking would thereafter be considered a Conditional Use, subject to Zoning Board of Appeal approval. The boundaries of the District, shown in Figure 4, encompasses all of Boston Proper, the Fenway, Columbia Point and part of South Boston. The Boston Redevelopment Authority (BRA), the City's planning agency, has the legal responsibility to advise the Zoning Board of Appeal.

The Board of Appeal makes the determination of conformance with the provisions of the code, that:

- the site is an appropriate location for the use, and will not adversely affect the neighborhood;
- there will be no serious hazard to vehicles or pedestrians from the use.

Those provisions specific to the Restricted Parking District, of which the facility must meet one or more of the conditions are:

a. It will serve a traffic demand not adequately provided for by public transportation; or

b. It will replace existing off-street parking spaces in one or more nearby parking facilities, or it will replace legal on-street parking spaces that have been physically eliminated through permanent modification or demolition; or

c. It is accessory or ancillary to a use which by its nature does not contribute significantly to traffic flows during peak traffic periods; or

d. The facility constitutes a temporary parking lot use of land and that serious intent to reuse the land for an allowed use within a specified period of time has been demonstrated to the satisfaction of the Board of Appeal.

In addition, other conditions may be attached to the parking facility, in order to "assure harmony with the general purposes and intent of this code," including:

- screening of parking areas with walls, fencing, planting, etc., from adjoining lots or the street;
- limitation of size, method and time of operation;
- regulation of number, design and location of access drives and other traffic features.

The Zoning Code also contains regulations regarding signage (a blue rectangle with the letter P must be placed at every entrance to a parking garage or lot); traffic visibility around corners; and imposes a minimum width of 10 feet for a driveway.

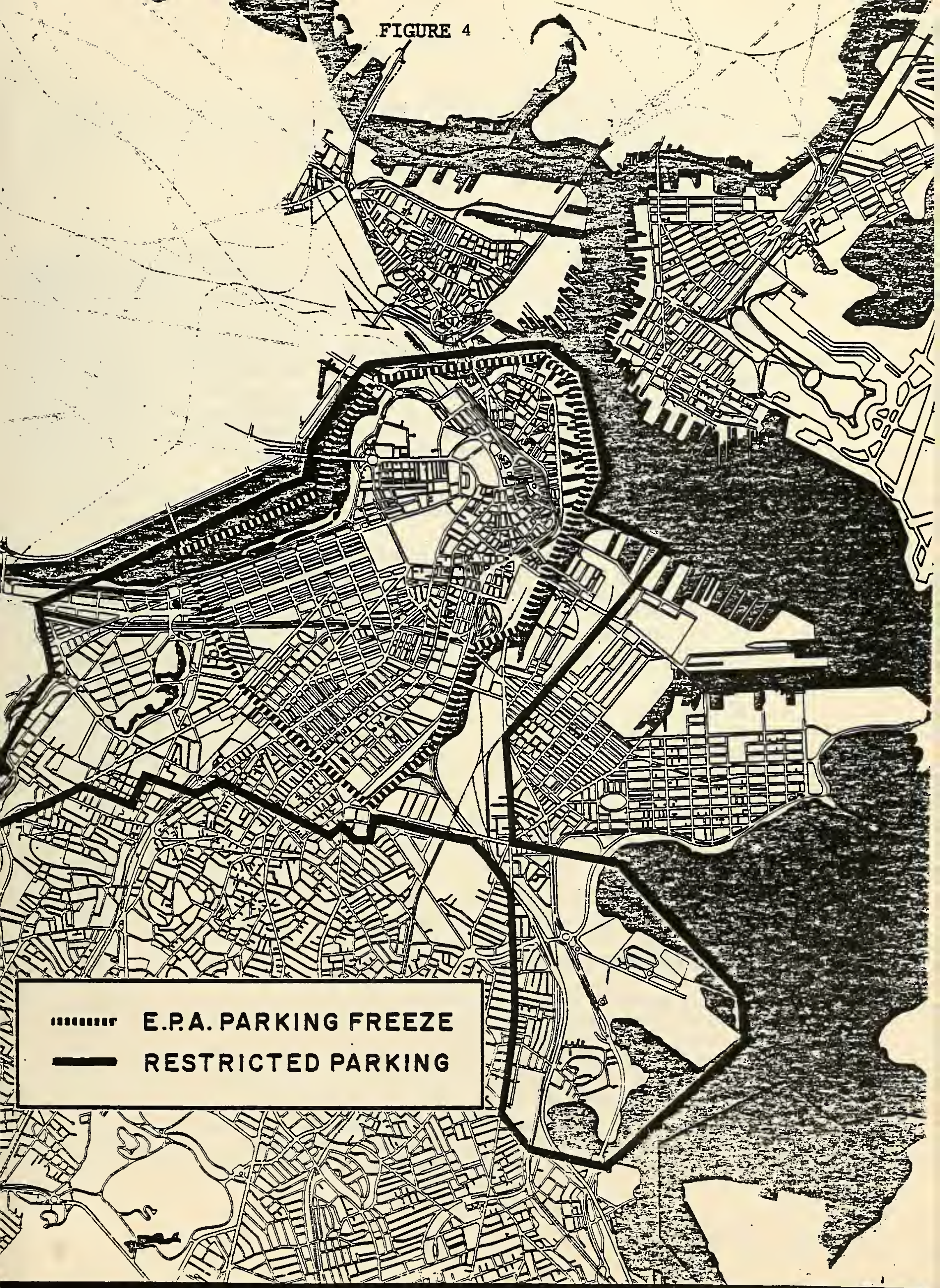
3. Air Pollution Control Commission Criteria

The APCC criteria apply to all facilities within the Parking Freeze district, which coincides with the area known as Boston Proper (see Figure 4). Facilities which intend to be open to the general public and charge a fee are those which must apply to the APCC for a permit in order to commence operation or add to the number of existing spaces. If the general public is effectively excluded from using the facility, for example, in resident-only, guest-only or employee-only parking, an exemption from the freeze must be obtained from the APCC. If the APCC is satisfied that mechanisms will be implemented which ensure restricted use, an exemption is granted.

The criteria for issuance of permits were designed to emphasize design and traffic management factors, in accordance with policies developed through BTPR and subsequent studies. They include that an applicant facility:

- Be located where it will not contribute significantly to peak-hour traffic flows and where surrounding sidewalks and streets can adequately accommodate pedestrians and vehicular movements;
- Provide justification of the need for such a facility, such as a deficit of parking in the vicinity, or that the facility directly serves surrounding development, and demonstrate that its design is appropriate and consistent with its surroundings;

FIGURE 4



- Be in conformance with City planning policy, which is to locate facilities on the fringes of the Downtown, reducing peak-hour traffic on interior downtown streets, and to encourage short-term, rather than all-day commuter parking.

4. Design and Operation Criteria

The City Public Works Department, Building Department and Traffic & Parking Department have policies and standards which govern the design and operation of parking lots and garages. Major concerns of the Public Works Department with regard to parking facility layout have to do with the location of curb cuts and curb radii. Plans for curb cuts must be reviewed and approved by a senior engineer in the department. Curb cuts for a parking facility driveway should be located at a minimum of 40 feet from the street intersection, measured from points of tangency. This distance allows for a queue of two automobiles on the street, before interfering with the intersection. Table 1 displays some of the recommended dimensions for parking lot layout from the PWD.

The Traffic & Parking Department rules regulating Open-Air Parking Spaces (lots) include requirements for:

- clear delineation of parking spaces and lanes for ingress and egress;
- wheel stops or other barriers to enforce parking lot boundaries abutting public ways, alleys and buildings;
- the maintenance of aisles as shown on the layout plan for the license application; and
- a sign displaying the operators' license number, capacity of lot, hours of operation and rate schedule.

The Massachusetts State Building Code's design standards adopted by the City Building Department as they relate to garage structures are primarily concerned with fire safety, i.e., drainage of oil, fire walls, etc. Some other standards include:

- Enclosed and below grade public garages must be equipped with mechanical ventilation adequate to provide six air changes per hour, and be in operation at all times while people are within the structure. (414.3.1)
- The first floor construction of public garages shall have no less than two means of egress from building. (414.2.2)

B. Design Guidelines from Parking Literature

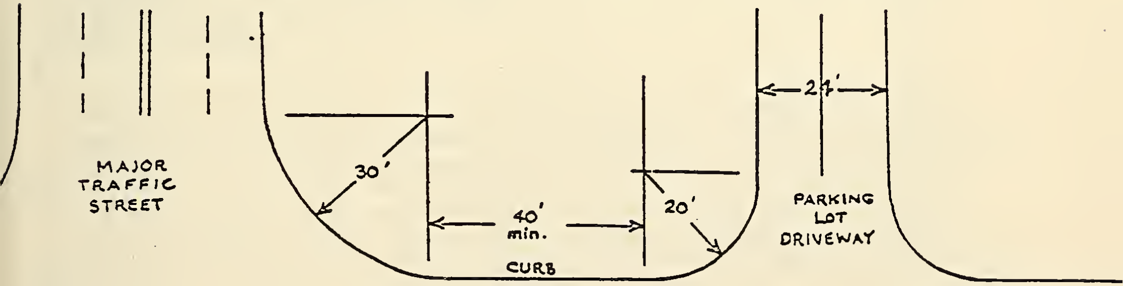
Design standards which are relevant to this study are those pertaining to moving cars smoothly in and out of a parking facility. Much of the literature is concerned with parking garages rather than with parking lots, since the latter tend to have smaller, more simple layouts, are less land intensive and thus pose less of a design challenge than garages. Dispersion of auto emissions is also quicker because of the lack of enclosure. However, faulty design of lots can also contribute to congestion, and there are many problems of ingress and egress that are shared by both lots and garages. Also, almost all of the recent parking standards

TABLE 1

OFF-STREET PARKING

	Parking	
Dimension	90°	60°
Width of Driveway & curb cuts (2-way)	24'	24'
Interior roadways	24'	24'
Width of driveway & curb cuts (1-way)	20'	20'
Parking aisle width	24'	18'
Stall Length (perpendicular to aisle)	18'	19'
Stall Width (parallel to aisle)	9'	10'5"
Actual width of stall	9'	9'
Median Depth (if provided)	4'	4'
Unit parking depth (stalls-aisle-stalls)	60'	55'
Minimum distance of curb cuts from street intersection	40'	40'
Curb return at public streets	20'	20'

Note: As shown in diagram below, distance of curb cuts from intersection is taken between the respective points of tangency.



and literature are concerned with self-park operations, typical of many lots and almost all garages. Since Boston does have several large mechanical garages and valet parking lots, these will be discussed in the next section.

The design features of parking facilities which are most relevant to traffic congestion and queuing can be viewed as:

1. ingress conditions;
2. internal traffic flow; and
3. egress conditions

1. Ingress to Parking Facility

Most modern parking garages and self-park lots feature automatic ticket dispensers which are either loop-activated by the presence of the vehicle, or require the motorist to press a button to obtain a ticket. It is crucial that curbs or other structural features be placed so that the motorist is guided close enough to the ticket machine to be able to take the ticket without leaving the vehicle. Since queuing on entry often occurs as a result of factors such as high rates of arrivals within a short time, the length of the gate transaction, or backups within the facility impeding movement through the gate, it is necessary to have some reservoir space, off the street, to ensure that there is as little interference with street traffic as possible.

The ENO Foundation handbook on parking planning and operation suggests that one inbound lane be provided for every 500 spaces in a facility that caters to long-term parkers, and one lane for every 600 spaces in a shopper-oriented facility.[3] Presumably the peaking of arrival rates for long-term parkers (workers) results in the greater processing requirement for those users. Another publication recommends that one inbound lane be provided for a garage with a capacity of 300-500 cars.[4] It has been reported that "as many as 660 vehicles/hour have been counted to enter through automatic ticket dispensers under conditions of constant waiting lines," but a typical design capacity is 400 vehicles/hour.[5]

Reservoir standards are more difficult to find, and observations in the field have located new facilities with almost no reservoir space between the ticket machine in the street, such as at the Dock Square (Quincy Market) Garage. Two to three car lengths should be the minimum provided, however. It is suggested in the literature that during peak periods an attendant should pull the tickets for the motorist to speed up the transaction, or that the machine be relocated farther into the facility during peak times to allow cars to queue within the garage rather than on-street.[6]

2. Traffic Flow within the Facility

After passing the entrance, the motorist is faced with the choice of where to go. In some larger facilities, there are indicators which direct drivers to certain areas or floors. Sometimes an indicator, either electronic or manual such as a sawhorse, will inform that a floor or area is full. However, these indicator systems are useful only in garages where access to certain floors can be blocked. In many facilities, particularly smaller ones, the ramp design is such that all floors must be travelled until a parking space is found. This type of layout is generally inferior from an air quality point of view because cars travel a greater distance at a slower speed while hoping to spot a space, or sit and wait for a car to back out, perhaps blocking those behind from proceeding. In garages with flow-through ramps and good attendant surveillance, cars can be directed to floors with vacancies, travelling a shorter distance with less idling.

Larger facilities, particularly those with more floors, should have express exits, also known as drums or spirals. Placed on the side of a facility, the ramp spirals down the facility, ending on the exit floor, thereby providing an alternative to travel through each floor. Because of longer time needed for the backing out maneuver, the potential for delays at peak exiting times are greater than in entry. Therefore, express exiting is much more necessary than express entry as a congestion-reducing technique.

The extensive discussions in the literature of the advantages of different angles of parking spaces are not of particular concern here; however, one-way aisles appear to contribute less to congestion than two-way traffic because of generally superior sight lines while backing into and out of spaces, and better effective turning radii. Depending on the particular layout of the garage, the distance travelled from the ramps to the floor while searching for a space need not be particularly longer with a one-way pattern than with a two-way.

In some complicated layouts, unnecessary cruising can be caused by inadequate signing. Particularly for infrequent users, clearly marked exits, express ramps, and directions to the adjacent floors labeled "Up" and "Down" can reduce the likelihood that a motorist will be caught "doing the loop" around a floor.

3. Exiting

Most garages experience exiting peaks, and efficient discharging of automobiles is required to minimize queues at the exit gates. The procedure for self-park facilities is fairly standard - the motorist gives the cashier the ticket, the amount due is announced by the cashier or an electronic sign, the motorist pays, and then is permitted to exit, frequently after a gate arm is raised. Guidelines for the number of exits provided range from one for every 200-250 car capacity, or two exits for every entrance.[7&8] Other guidelines state that the number of required exits can be determined by using a 40-50 minute exit time for discharging the garage's entire capacity,[9] or "ideally, garages should be able to fill or empty completely within one hour or 60% in one-half hour."[10]

It is noted that a cashier can process 180-225 cars per lane per hour with a simple rate structure, whereas a more complex rate structure can reduce this capacity.[11] (This will be discussed further in the next chapter.) Other sources report that a typical cashier can handle 150-200 cars per hour.[12] In order to expedite this transaction during rush hours, an attendant can note the amount due on the tickets of cars waiting in line, so that their money is ready by the time they reach the exit.

The traffic conditions on the street of egress also affects the discharge capacity of a garage. The volume and speed of traffic, sight distance of exiting drivers, pedestrian volumes and left-turn regulations all can contribute toward delayed egress of vehicles from a parking garage or lot. It is recommended that at least one or two car lengths be provided as a reservoir between the street and the end of the gate,[13] so that vehicles attempting to join the stream of traffic do not cause backups which extend to the cashier's gate.

CO emissions are worst during peak exiting times. Generally, there is more peaking of exiting vehicles than entering, and CO emissions are greater during cold start conditions, more commonly a feature of exiting cars than those entering. The dispersion of emissions is further reduced in a structure, as compared to open air parking. A rare mention of air quality and parking in the literature was found in the context of CO emissions and the danger to cashiers who are exposed to large amounts of CO in the evening peak hours.[14]

C. Summary

The guidelines, standards and regulations presented in this chapter provide a basis by which to evaluate the operation and design of parking facilities in Downtown Boston. Regulations and standards used by the City in the various permit processes for approvals of parking facilities are mostly concerned with safety. The safety of the parking motorist is protected by adequate sign distances, ramp grades, aisle widths, parking space dimensions, ventilation and the absence of fire hazard. The pedestrian's safety is considered through sight distance. Aesthetics, land use planning, compatibility with adjacent uses and contribution to traffic flow are the other factors included in written regulations and standards.

Informal standards are exercised through the discretion of the various review agencies. Typically, these may involve requiring more than the minimum standards if the circumstances so warrant, or imposing requirements for approval which are not necessarily contained in written regulations or standards, such as locating the major entrance/exit on a one-way street, when possible.

Guidelines found in the parking literature were primarily geared towards efficient design which would maximize the number of parking spaces which could be provided in a given area, and to minimize operating and construction costs.

Almost no mention was found of the relationship between operating characteristics and air quality, although mitigation of congestion for its own sake is a recurring theme. In the following chapter, actual observations of several parking facilities are described, and salient operating characteristics with respect to queuing and air quality are identified.

IV. CHARACTERISTICS OF PARKING FACILITIES IN BOSTON PROPER

A. Types

There are three functional types of parking facilities in Boston Proper. They are: mechanical garages, self-park lots and garages and valet lots. Another way to look at parking facilities would be to assume two categories: self-park and attendant park; but there are enough differences between the operation of mechanical garages and valet lots to warrant separate categories.

1. Self-Park Facilities

Self-parking garages and lots comprise the majority of the 55,000 parking spaces in Boston Proper, and almost all of the most recently developed spaces. The reasons for the relative increase in self-parking facilities is mostly attributable to rising labor costs, but another factor is the preference of motorists for parking their own cars.

The major advantage of self-park operations is that there is no time-consuming shift of driver as in valet parking. Some disadvantages include the greater requirements for parking space dimensions, and less surveillance and personal security. In and out characteristics can be better or worse than valet parking, depending on the individual operation, as discussed below.

Most self-park lots and garages favor a pay-upon-exit system with graduated hourly rates. A time-stamped card is obtained upon entry, and the appropriate fee is paid at the exit. Because of the "complexity" of the exit transaction, it frequently causes queuing. However, some pay-as-you-leave ramp garages avoid exiting congestion by requiring payment prior to retrieval of the car at the cashier's booth inside the structure. A receipt is given, the motorist retrieves the vehicle and presents the receipt to the attendant at the exit. This technique displaces the queuing from the automobile exit to the cashier's window, definitely having a positive effect on air quality.

An alternate form of fee collection is payment upon entering. Pay-as-you-enter is the favored method of fee collection for night parking and special events, eliminating the need for attendants to remain late, particularly when the parking will be of more or less predictable duration such as for sports events. Only two garages in Boston Proper operate on a pay-as-you-enter basis during the day. These garages have been targeted repeatedly as the cause of extreme congestion at certain intersections in Downtown and this method of fee collection is thought to be a contributing factor.

Some of the parking facilities in Boston may not collect all fees on a daily basis. A monthly sticker may be used, which allows the attendant to wave the car through the fare collection procedure, or a card is accepted by a machine which opens a gate and allows a car to pass.

2. Mechanical Garages

There are over 37,000 spaces in parking garages in Boston, and of these 2,875 are located in five mechanical garages. An older technology, mechanical garages operate slowly, but require less land per space than garages with ramps. The operation of mechanical garages is standard: the motorist drives up to an elevator bay, or if occupied, reservoir spaces (often the sidewalk), obtains a ticket, leaves the keys in the car, the attendant drives the car onto the elevator and into a stall, and then returns the elevator to the ground level. Because of the time needed to complete this cycle, queues often occur in the street during peak entering times. Attendants frequently jockey cars around the property to reduce the on-street queuing. In order to retrieve the automobile, the driver presents the parking ticket to a cashier inside the facility, pays, and gets a receipt which is given to the attendant who then delivers the automobile. Almost no queuing of automobiles occurs during the exiting, only queuing of people, since the rate of departure is limited by the retrieval time for the automobile. Consequently, the worst queuing problems at mechanical garages occur in the morning peak, whereas the evening peak presents the worst conditions at most ramp garages.

3. Valet Parking

Valet parking is typically used in small lots where space is at a premium, which is the predominant condition in the Downtown. Valets are able to park cars closer together than is felt to be safe for the general driving public, and also retain keys so that few aisles are needed and maximum area is used for parking. Fees are paid upon exit, usually to a cashier or attendant prior to the retrieval of the car. In contrast to the two previously discussed types of parking facilities where the worst queuing occurs in the morning or evening, the worst queuing (for entering vehicles) could well occur during the midday, because of more short-term use and thus extensive in and out activity.

If insufficient space is left for aisles or reservoirs through overparking, then the jockeying of automobiles takes place on the sidewalk, driveway, or in the public street. However, if operated correctly, valet parking does not contribute excessively to air pollution as payment and ticketing is typically transacted when the car and engine is turned off, unlike other types of parking. Also, cold starts and jockeying can be kept to a minimum when all-day parkers are "boxed-in", short-term parked cars are arranged in rough order of their parking duration, adequate reservoir space is provided for incoming cars, and no queuing and temporary parking of cars on street occurs.

B. Markets Served and Locations

Within Boston Proper, the limits of this study, there are approximately 55,000 off-street parking spaces. Of these 55,000, 35,000 are open to the general public, 17,000 are reserved for employees of certain establishments, and the remainder are residential, hotel, customer and visitor parking.

No statistics are available to tell us exactly how many of these 35,000 spaces are used by employees, but enough evidence exists to say conclusively that the vast majority of these spaces are filled early in the morning, presumably by commuters - not by shoppers or other short-term users.

Several recent surveys of parking facilities show high percentages of occupancies by 10:00 a.m. in the morning, indicating high all-day commuter use. Some of this information is summarized in Table 2.

This is relevant for establishing the extent to which peaking occurs in parking facility arrivals (and departures), rather than being in a state of constant demand during the day.

Through the administration of the Zoning Code and APCC criteria, there has been a slight shift in the pattern of location of parking lots and garages. Once randomly located, now emphasis is placed upon locations with direct connections to the regional highway system, with the intent of limiting traffic on the internal streets of Downtown. This policy has been in effect since 1973, but it is sometimes a matter of opinion what constitutes direct highway connections, since few locations in crowded Boston are more than several blocks away from a major arterial. But generally, parking facilities located on the periphery of Downtown are preferred.

C. Traffic Characteristics of Downtown Streets

It has been mentioned earlier in this paper that the act of parking contributes to degradation of air quality due to slow speeds and idling, but parking may also interfere with automobiles on the street system and cause back-ups to occur on the street. It is easy for a "jam" in one street to feed back through the system because of the heavy traffic flow in relation to the street capacity. One measure of this is "level of service" which ranges from "A" or free-flow conditions to "F", or little movement. Many of the major streets in the Downtown operate at levels of service D and E during the peak periods, which does not offer much reserve to absorb additional delays due to parking facility queues on the streets.

Thus, as cars queue to enter parking facilities, first in the driveway, then in the parking lane of the street, then back through the intersection, the cross street traffic can be impeded, which leads to impatient drivers ready to block the intersection when they have a chance to get through.

This common scenario is one that produces poor spot air quality, as the jammed, idling cars emit carbon monoxide into the air in concentration, and cause delays to a wider sphere of vehicles than those intending to park. Double-parked queues for entry into parking facilities, not a rare sight, effectively reduce the available travelway by one lane, thus reducing the level of service at intersections which require that additional lane in order to operate effectively in the peak. Similarly as described above, this situation also leads to congestion and excessive CO emissions.

Table 2

Off-Street Parking Supply and Use - 1982

	# of Spaces	% Occupied @ 10 A.M.
Financial District/South Station	5,221	90%
Government Center-West End	7,190	89%
North Station	1,145	90%
Retail/Park Square	4,604	77%
Boston Common	1,500	102%
Back Bay	6,939	89%
Copley/St. Botolph	275	37%
Waterfront	1,307	46%
Fort Point Channel	3,496	101%
TOTAL	31,757	87%
	Occupied at Noon:	93%

From: Draft Report, Parking in Central Boston: Present Conditions, Future Needs and Policy Options Preliminary Assessment, November, 1982. Cambridge Systematics & Vanasse/Hangen Associates

V. FACTORS AFFECTING THE EFFICIENCY OF PARKING FACILITIES

A. Introduction

The purpose of the field studies was to measure and observe the operation of different types of parking, in order to distinguish among operational characteristics which contribute to efficient operations or problems in a parking facility. It was determined that we would examine problematic facilities first, and acquire familiarity with the operations and then select more efficient garages or lots with similar characteristics so that differences could be highlighted and conclusions made.

A preliminary list of facilities that were known "troublemakers" was drawn up. This list included only garages; Winthrop Square, Post Office Square, UnderCommon, Kilby Street and Dock Square. These garages were responsible for notorious congestion - the first 4 in the morning peak, and Dock Square during midday. (Figure 5)

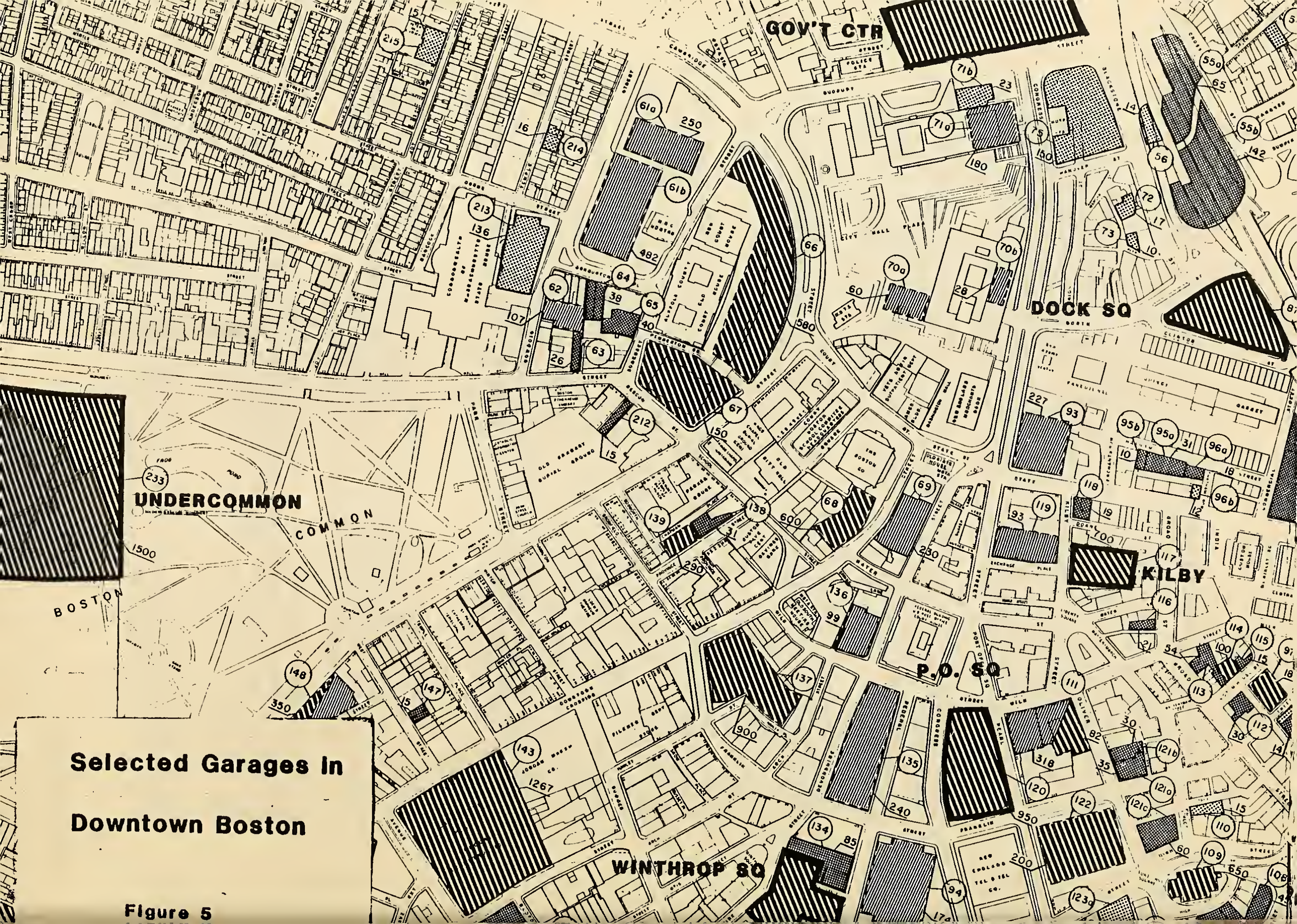
Field observations affirmed the existence of queuing at these five locations, and measurements were made of the transaction times for entry into the garages. During these studies, the garage operation was examined to determine characteristics which may hinder or help the smooth flow of vehicles into and out of a facility.

Parking lots, in general, did not cause the magnitude of queuing problems that garages did. First, the capacities are far smaller, and thus generate less demand. Also, most of the parking lots in the heart of Downtown where streets are most congested have valet parking and proper operation allows sufficient reservoir space for cars to be left on the parking lot property and reparked by the attendant. Midday operation of these lots appeared to cause more interference with traffic flow, since by that time the lots had higher occupancies and less maneuvering room, so vehicles might have to wait on street until cars were jockeyed around the lot. Also it was observed that cars will queue on-street to await a vacancy in a "filled" lot, often causing traffic congestion. But parking lot-related queuing and congestion did not seem to approach the levels observed at garages.

The fundamental relationship between efficient parking operations and air quality is that idling and stop-and-go conditions result in more emission than under conditions of free-flow. A poorly designed or poorly operated facility will not process incoming vehicles rapidly and resulting delays can cause reverberations throughout the traffic system.

Discussed below are occurrences contributing to excessive automobile emissions: entering queues and exiting queues, both facility-related conditions; parking-related delays that take place outside of the facility but are not a result of the design of a particular facility; and "cruising" for parking.

These major parking-related causes of excessive vehicular emissions have themselves been identified as being caused by a variety of other factors. Some of these factors can be quantified and thus assessed as to their



Selected Garages In

Downtown Boston

Figure 5

importance; most cannot. However, an understanding of all possible factors which may affect parking facility operation will assist designers, operators and municipalities in reducing CO levels in the vicinity of parking facilities, and reduce interference with general traffic flow.

B. Entering Delay Factors

1. Number of Entrances

In Section II.B, a reference stated that one inbound lane be provided for every 500 spaces in a facility that caters to long-term parking. In Downtown Boston, almost every large parking facility caters to long-term parking. Restrictions on the growth of parking spaces, despite large gains in Downtown employment, has led to an increasing percentage of parking spaces utilized by commuters. Thus, in most large parking facilities, peaking is quite pronounced. This phenomenon is responsible for much of the entering delay experienced into parking facilities.

Several garages notorious for long entering queues are compared to similar sized facilities with comparable markets which were observed to operate smoothly.

Long Entering Queues		Limited Queuing	
# of entrances/capacity		# of entrances/capacity	
Winthrop Square	2/1150	Motor Mart	2/900
Post Office Square	2/950	Woolworth's	2/900
UnderCommon	2/1500	Government Center	4/1865

From this small sample, the ratio of entrances to capacity among "problem" garages are 1/575, 1/750 and 1/450, whereas the other sample ratios are 1/450 and 1/466. But it should be noted that both Winthrop Square and Post Office Square garages do not operate two entrances for the duration of the peak period so those ratios are really smaller. Although the number of entrances is clearly of major significance for queuing, the numbers of vehicles within a given time period which desire to pass through the entrances is also an important factor.

Entering counts, by 15 minute intervals, were taken at several facilities to determine the effect of peaking on queues. One garage, Winthrop Square, observed to be the cause of long queues and traffic disruption, exhibited the following pattern of arrivals at one entrance on one day:

7:01-7:15- 41
7:16-7:30- 53
7:31-7:45- 41
7:46-8:00- 42
8:01-8:15- 78
8:16-8:30- 80
8:30-8:37- 23 (this entrance closed)

During the peak 15 minutes, 80 vehicles entered the facility, at a rate of 5.3 cars/minute, or 1 car/11.3 seconds. It should be noted that, although on-street queues of 17 vehicles were observed on this day, even during the peak 15 minutes there were some brief times when no queues existed. This processing rate of 320 vehicles per hour (if the peak 15 minute demand was maintained for one-hour) is not the full processing capability of this gate, although our recorded rate compares quite favorably with published standards.

To reiterate the point that this gate was not operating at full capacity even during the peak 15 minutes, we timed the transaction of 26 vehicles entering this facility. We measured the time at which the front of a vehicle passed the beginning of the transaction area, until the end of the vehicle passed the end of this area, not timing any gaps. The areas were delineated so under queuing conditions there would be no lapse in timing. The average gate transaction time per vehicle was 9.27 seconds, somewhat less than our 15 minute average time of 11.3 seconds.

Rounding off conservatively, 6 cars per minute, 90 per peak 15 minute period could theoretically enter this facility. This is less than the number of cars that actually did arrive. So why were long queues present?

Clearly, arrivals of cars are not distributed smoothly during the peak 15 minutes. Cars often arrive in clusters, perhaps as a result of the metering effect of a traffic signal. Cars may not be able to proceed smoothly to the driveway and gate, and these factors will be discussed below, as well as the effect on queuing of different transaction methods.

2. Type of Transaction at Gate

Type of transaction at gate is of extreme, or secondary importance, depending on the specific situation. At the extreme end, the "transaction" of handing one's car over to an attendant is often quite time-consuming and can cause considerable on-street queuing, as occurs at most mechanical garages. A view of Table 3 shows exactly how time consuming this can be. On the other hand, the difference between a loop-activated gate and a press-button gate ticket transaction appears to be minor. However, our unsophisticated stop-watch method of timing becomes less reliable in differentiating between short intervals than longer ones.

Mechanical garages typically have more entry points than do self-park facilities. Six is the average for the three facilities surveyed, giving them a significantly smaller hourly processing capacity than self-park facilities because of their slow intake. Despite the oft-made claim that there is not sufficient off-street parking in Boston to meet the demand, the typical occupancy rate at mechanical garages is 2/3 capacity. One possible explanation is that the queues are so long that potential parkers are deterred from using the facility.

Looking at the self-park facilities, the hourly difference in processing capacity per gate between loop-activated and press-button gate is 40 cars per hour, or 10 per 15 minute period. This factor alone should not really influence queue formation. However, our timing of the pay-upon-

Table 3

Sample Entering Transaction Time and Facility Capacities

	Average	Minimum	Maximum	Average Cars Per Hour Per Gate*	# of Gates Open During Peak	Processing Capacity Per Peak Hour
	in seconds					
Mechanical 1	87	70	102	41	6	246
Mechanical 2	77	55	137	47	6	282
Mechanical 3	69	69	114	52	6	312
Pay Attendant Upon Entering	9.3	5.0	19	388	2	776
Loop Activated Gate 1	8.2	5.0	12	439	2	878
Press Button Activated Gate	7.0	4.3	12	514	2	1028
Loop Activated Gate 2	6.5	4.0	11	554	2	1108

*Based on the average sample transaction time found in this study.

entering method, used at Winthrop Square, results in a reduced processing capacity of 126 - 166 fewer cars per hour than these above ticketing methods.

It could be concluded that if Winthrop Square would change over to pay-upon-exiting 28-38 more cars could pass through one gate during the peak 15 minutes, representing an increase of 35%. Since queues at any one gate were never observed to be that high (although queues may approach that level on some occasions), it seems that queues would decrease substantially.

It happens that we had an opportunity to test this hypothesis. Shortly after we took the above pay-upon-entering measurements, the garage switched over to a gate system. The average transaction time decreased to 8.2 seconds; however, queues of 25 or more cars were still found, at times. This decrease in transaction time was less than anticipated. Small delays as result of pedestrian travel were observed, as well as delays at gate because of internal backups. However, this finding points to the importance of the measure relating demand to the number of entrances in the facility. Small changes in transaction times can affect the number of cars processed in one hour, but depending on the demand for the facility, the actual reduction in queue length may be imperceptible.

3. Other Factors

Two other factors were observed to have a small effect on entering delays. Pedestrian traffic across the sidewalk can be significant in some locations. However, the effect is minimized by aggressive drivers who closely tail the vehicle in front to move into gate reservoir position. Pedestrians will detour around vehicles, and when there is a break in the pedestrian flow, a platoon of two or three vehicles will move into the gate/reservoir area.

The internal layout of a garage can affect delays in vehicles parking in the facility. Internal queuing can be caused by the slow movement of vehicles searching for spaces, particularly after a facility is nearly full, or if there is insufficient space for passing a backing-out car, or one waiting for a parking/unparking maneuver to be completed.

4. Summary

A summary of these entering delay factors is found in Table 4.

C. Exiting Delay Factors

Exiting delay factors have slightly different air quality implications than entering factors. Entering queues can impact general street traffic, but exiting queue impacts do not generally extend beyond the property of the facility. In parking lots, both entering and exiting queues spew emissions into the open air; in garages, most of the entering queue length will occur outside, whereas exiting queues will almost always occur within an enclosed area, having different dispersion characteristics.

Table 4

Entering Delay Factors Summary

Casual Factors	Comments
1. # of Entrances peak arrival volumes	Clearly the most important delay factor. A gate can process anywhere from 40 cars/hour in a mechanical facility to 300-600/hour for self-park. Excessive queuing can be alleviated by the opening of an additional entrance, or by provision of sufficient entrances in new parking facilities.
2. Type of transaction at gate	The type of transaction at the gate can influence processing times by anywhere from 40-166 cars/hour. Quickest transaction is flashing of passes; then manual pulling of ticket (unobserved); loop activated ticketing; press button activated ticketing; and finally pay attendant upon entering.
3. Pedestrian volumes across curbcut	Potential delay of several seconds per car; observed up to several seconds of delay per group of 2-3 cars. Could theoretically reduce processing capacity by about 60 cars/hour; however, in Downtown Boston, pedestrian volumes are rarely constantly high, but occur in surges. More typical reduction in entering capacity of 15-30 cars/hour.
4. Internal layout	Internal delays can be caused by slow movement of vehicles searching for spaces, particularly after garage is nearly filled, and if there is insufficient space for passing a backing-out car, or one waiting for maneuver to end. Potential delays of several seconds or more per vehicle encountering these conditions.

The factors contributing to existing queues include the number of gates in relation to existing volumes, type of transaction which occurs at the gate, pedestrian volumes across curb cut and internal layout, all discussed in relation to entering. But there are several additional factors which come into play for exiting traffic and they will also be examined.

1. Number of Gates

Although peaking is generally more pronounced in the evening, it was not verified by our measurements. Exiting was observed at several facilities, and these volumes were considerably less than entering volume. Internal queues did not appear to be excessive.

Peak exiting volumes for several observed facilities are:

Winthrop Square (one gate)	Government Cent. (two gates)	Dock Square (two gates)	Woolworth's (two gates)	P.O. Sq. (two gates
3:45-4:00 - 21	4:56-5:11 - 70	4:40-4:55 - 31	4:15-4:30 - 36	
4:00-4:15 - 40			4:30-4:45 - 56	
4:15-4:30 - 35				5:00-5:15
4:30-4:45 - 40				4:30-4:15
4:45-5:00 - 36				
5:00-5:15 - 62				
5:15-5:30 - 41				

At Winthrop Square, the longest internal queues observed were 5-6 vehicles; at Government Center 4-5 per gate; Dock Square 6; and Woolworth's 2-3. The longest time in a queue at Dock Square was 1 minute, 50 seconds.

Single purpose parking facilities would experience sharper exiting peaks, for example those serving sports events or one large employer who did not stagger shifts.

Some exit ratios per capacity were Winthrop Square, 2/1150; Government Center, 4/1865; Dock Square, 2/600; and Woolworth's, 2/900; or a range from 1/300-1/575. This is inferior to the standards cited in Section III.B.3 of 1/200-250 vehicle capacity. Again, the number of portals cannot be examined in isolation; we will next look at type of transaction and fee structure as it affects exiting vehicles.

2. Type of Transaction

The major transaction method is to: submit ticket to cashier; it is manually or automatically priced; the price is conveyed to motorist verbally or through readout; money is exchanged; and a gate opens to let the vehicle pass. In Winthrop Square and Post Office Square Garages the motorist pays upon entering and a colored dated ticket is submitted to the attendant to verify that the length of stay has not exceeded the boundaries of their parking "day". In Motor Mart and mechanical garages, the driver pays prior to retrieving the car - an attendant collects the ticket at Motor Mart's exit, and in mechanical garages the attendant retrieves the vehicles.

Table 5

Sample Exiting Transaction Time & Facility Capacity

Facility	Aver. Time in Seconds	Min.	Max.	Av. Cars Hr./Gate	# of Gates	Peak Hour Facility Discharge Capacity	% of Total Capacity
Gov.'t Center	21.0	6.5	101	171	4	684	37%
Woolworth's	23	14	39	156	2	312	35%
Dock Square	20	9	34	180	2	360	60%

Our observed values are less efficient than a published standard for exit gate operation of calculation and collection of variable fee of 200 cars/hour. For collection of pre-paid receipts, it is cited that 375 cars can pass through a gate in one hour, although our observations at Motor Mart lead us to believe that the number could be much higher -- in the order of 600 per hour.

Another reference states that "garages should be able to fill or empty completely in one hour or 60% in one-half hour"[16]. Our sample data does not find the studied garages to be that efficient, yet queuing at exits doesn't seem to be a constant nor severe problem at observed facilities.

3. Fee Structure

Judging from the amount of variation between average and maximum exiting transaction times, and from an observation of people's movements, it was hypothesized that there would be a difference in peak and off-peak transaction times. This would be due to the peak period exiting commuter, who has reached the daily maximum, generally calculated in even dollars, and knows with certainty the payment required since this is most likely a daily activity.

The parker leaving the facility in the off-peak may be an irregular patron, may not be familiar with the fee structure, and the off-peak fee most likely will require change on one side of the transaction - thus a slower process.

This assumption proved to be correct in our limited sample. Government Center, a $4 daily charge, or $1/half-hour, had off-peak average exit transaction times of 24 seconds, somewhat higher than the 21 seconds in the peak. Woolworth's, with a slightly more unwieldy fee schedule of 1.50/half-hour, $7 daily maximum, had off-peak transaction times of 32 seconds, almost 40% higher than the peak average of 23 seconds. Evenness of fee and peak vs. off-peak transaction time do have some, albeit a slight influence over exiting times.

4. Traffic on Street of Egress

If traffic on street of egress is heavy, cars exiting a facility may have difficulty joining the stream of traffic and thus can prevent other vehicles from passing through the gate. This was observed to happen in only a few instances.

This situation can be avoided by exiting onto one-way streets, prohibiting left-turns onto two-way streets, or if traffic warrants, placing a signal upstream.

In the review of a proposed facility, it should be understood that a car will pass through the gate every twenty seconds or so (based on gate type and transaction) and attempt to join the stream of traffic. For example, if a constant stream of traffic on the street of egress during the peak is metered by a two-phase signal with a 30 second green time, then the reservoir space between the gate and the street should be two car lengths long. This could permit cars to wait for access to street without blocking gate. Generally, at least one car length of reservoir space should be provided between the gate and the street.

5. Pedestrian Volumes Across Curbcut

Even under conditions of extremely heavy pedestrian volumes, there was a minimum of delay observed. The Pi Alley garage egress is located on Washington Street, where some of the largest pedestrian volumes in the City occur. Although there is not reservoir space for even one vehicle, and therefore delays in moving out into traffic will delay other vehicles from clearing the gate, infrequent delays of 10 seconds or less were observed. Since transaction time for the following vehicle at the gate would be about twenty seconds, it is unlikely that pedestrian delay would cause a back-up at the gate. A fortuitous combination of many pedestrians but few vehicles on Washington Street helped cars to move out of the gate position.

The heaviest pedestrian surges occur after sports events when great numbers of pedestrians attempt to cross streets at one time. The skill and aggressiveness of Boston drivers enables them to be relatively unimpeded by pedestrian flows, for example, when Boston Garden lets out. However, the parking facilities in the vicinity are pay-upon-entering, so that gaps in pedestrian flows are quickly seized upon and allow vehicles to typically enter traffic in quick succession.

Generally, pedestrian flows should not present a significant problem, unless extremely high constant volumes pass by parking facilities in the evening peak. The more crucial issue may well be that of ensuring pedestrian safety in the face of aggressive drivers.

6. Internal Design

Internal design issues relate only to ramp garages and include consideration of the layout of the aisles, and the amount of travel required to exit. Narrow aisles do not permit cars to pass those engaged in a parking/unparki maneuver. During a time when many cars are attempting to leave the facility, vehicles can face long delays, most particularly when traveling through a number of floors to get to the exit.

Express exiting alleviates this waiting by allowing vehicles to exit either through a helix (drum, spiral) attached to the side of the facility, or an internal ramp system that does not require cars to travel through aisles to get to the exit. Although there are positive air quality implications to express exiting, the incentive for incorporating this into design is to reduce driver aggravation and speed up the trip out of the facility. Again, in a competitive parking market situation, parkers could be expected to avoid facilities which cause undue delays, and owners/operators desire to attract patrons to their facility.

Under a controlled supply, it is less necessary to provide "amenities" to potential users since demand remains high, regardless. If a garage is over a certain size, say 5-6 stories, the City should look carefully at whether express exiting is warranted during design review.

7. Exiting Delay Factors Summary

A summary of these factors is found in Table 6.

D. Outside Facility Delays

Queueing and congestion on-street can occur as a result of parking facility operation, in particular during the morning peak. If cars cannot move into the garage as quickly as they arrive, and if reservoir space is insufficient, queues will form on-street. If cars are parked (illegally) in the curbside lane queueing cars will interfere with moving traffic. If arrivals greatly exceed processing capabilities, queues may lengthen until an intersection is crossed. Since many local drivers do not feel it is necessary to keep the intersection clear, cars may queue through intersection blocking cross traffic, resulting in a traffic "jam". Unfortunately, this scenario is not uncommon in Downtown Boston, and was discussed in the "Entering Delay Factors" section. However, another set of causes for on-street congestion was observed. These causes have less to do with the design or operation of a particular facility, but are more related to external factors - such as the behavior of motorists, system-wide availability of parking, or traffic regulations. The most significant occurrences in terms of air quality impacts is a situation where a motorist chooses to queue for entry into a garage or lot which is full. This not only results in excessive emissions from the vehicles in the queue, but often causes congestion to occur in general traffic. Several other factors which contribute towards delays to general traffic flow as a result of parking operations are discussed below.

1. Motorists Choose to Queue

One cause of on-street queueing is due to parkers waiting to enter through a gate which is "full" or "open at 8:00 a.m." Again, this bizarre situation is not uncommon to see on a daily basis in Downtown Boston. One such double parked queue was observed to include 20 cars, with cars beginning to arrive up to 30 minutes prior to opening of

Table 6

Exiting Delay Factors Summary

	Causal Factors	Comments
1.	# of exits Peak departure volumes	Generally traffic flow peaks more sharply in evening; however not in studied parking facilities, according to our findings. Peak exiting volumes per 15 minutes per gate were found to be about 50.
2.	Type of transaction	The arrangement where a ticket only is transacted and no money is quickest, the more typical transaction is submission of ticket showing time of arrival to cashier who computes amount owed, money is exchanged, and gate arm opens.
3.	Fee structure	Even dollar fees that do not require change are the quickest. Off-peak transactions are generally slower because of the greater uncertainty of amount due.
4.	Traffic on street of egress	Cars exiting parking facilities may have difficulties joining stream of traffic where volumes are heavy, and cause delays at gate. Adequate reservoir space, prohibition of left turns against heavy traffic, and location of exits on one-way streets can prevent delays at gate.
5.	Pedestrian Volumes across curbcut	Garage entrances and particularly exits should not be placed on streets of heavy pedestrian volume whenever possible.
6.	Internal design	Relates particularly to multi-storied ramp garages where express exiting may be warranted, if travel down through many floors are required.

an entrance, and ultimately interfering with the operation of the upstream signalized intersection. During mid-day this queuing in front of a "full" facility has been observed at both lots and garages. One particularly troublesome case of mid-day queuing has been at the Dock Square (Quincy Market) Garage, troublesome because of the reservoir holds only one vehicle, and the portal to the facility is merely two car lengths away from the intersection with a major artery. Through traffic is impeded as cars queue in the right lane of the artery for garage access, confusing those motorists who believe it is a right turn lane. Right-turning cars swerve out of the queue into traffic and make a right turn from the second lane. Congestion in two or three lanes of the Artery results.

Evidently, patrons are willing to wait in lines for what may be considered to be long periods of time to enter garages. Why?

a. Inadequate Knowledge

One reason posited for the frequent mid-day and evening queues for the D-10 lot (Quincy Market) and the Dock Square Garage is that these facilities are patronized by tourists and suburbanites who aren't familiar with the City, but can find their way to the Market and the adjacent parking. Unwilling to venture into the maze (and congestion) of Downtown streets to find alternative parking, they would rather sit in a line with engines running and eventually park close by to their destination.

More generally, it can be stated that people commuting to the City on a regular basis are familiar with parking in the vicinity of their destination. However, infrequent travelers to Downtown may not be familiar with more than one or two parking facilities; do not know Downtown street patterns; the precise location of their destination, or a combination of all three factors. The extent to which this occurs, and the effect on air quality is difficult to quantify, but it is likely that inadequate knowledge of the city and parking options does cause excessive emissions to occur.

b. Advantages that Outweigh Waiting Time

The major "advantage" of a parking location that causes cars to queue up is pricing differentials, although a secondary cause may be minimization of walking time. Several of the problem garages (e.g., UnderCommon, Winthrop Square, P.O. Square) in the Downtown are owned either by the City or by the Commonwealth and are priced, for contractual or bureaucratic reasons, below prevailing market rates. Using the traditional transportation definition of pricing, the cost of parking is the out-of-pocket rate plus some factor applied to the waiting and walking times. Because of this, the difference between a $3.45 daily fee and a $5-$7 charge makes it reasonable for some people who have a certain valuation of time to wait in line for up to 45 minutes.

c. Constrained Parking Supply

Another reason for mid-day queuing may be the perception that there are few spaces available and it wouldn't pay to "cruise" around to find vacancies. In some sections of the City, this is a valid perception.

The recent study shown in Table 2, found that mid-day noon occupancies in various sections of the Boston Proper is very high - averaging 93%. This apparent shortage of parking influences motorists to remain in line, counting on the chance that a vacancy will soon open.

A recent study of a large garage which is "full" by mid-morning has shown that there is some amount of turnover during the off-peak times. "Outs" range from 2 per 15 minute period between 9-10:00 a.m. to as many as 14 between 2-2:15. The average number of departures between 10:00 a.m. - 3:00 p.m. per 15 minutes is seven, indicating a queue of seven outside this facility, will on the average, be absorbed within 15 minutes.

The remainder of the delay factors pale in relation to the air quality impact of when a motorist chooses to wait in a long line. From an air quality viewpoint these above described scenarios are particularly noxious since 1) duration of idling is generally expressed in minutes, rather than seconds, as has been the basis of the gate transaction analyses, because of the cumulative nature of the queuing, and 2) not only parking-facility destined traffic, but general traffic flow is impeded, which can have far reaching implications particularly in the tightly orchestrated traffic system in Downtown Boston. As mentioned previously, because there is not much "slack" in the system during peak periods in certain sections of the City, disturbance in the flow can quickly back up and cause idling vehicles at many locations, rather than just one.

However, some other minor factors can help in reducing delays to general traffic. In decreasing order of importance, they are:

2. Traffic Regulations and Enforcement

The use of the curb side lane for reservoir means that the lane must be signed and enforced for no parking so that cars queuing for entry are not forced out into a travel lane. When queues extend into the upstream intersection, enforcement should keep the intersection clear for cross traffic movement.

Left turn prohibition and location of entrances/exits on one-way streets can expedite movement from and onto street.

3. Clear Signage

Clear directions to entrances and exits, particularly if choices can be made so as to avoid queuing, can be helpful.

These factors contributing to delay outside of the parking facility are summarized in Table 7.

E. Cruising for Parking

Although it is difficult to observe "cruising" as a phenomenon, it is likely to expect motorists, when faced with "full" signs, would drive off in search of vacancies. One morning, while observing a particularly lengthy queue to a closed entrance, cars were seen to leave the line

Table 7

Outside Facility Delay Factors Summary

Casual Factors	Comments
1. Motorist Chooses to Queue	When a facility is closed, motorists may choose to wait in line until the facility lets cars in again. The resultant on-street queuing can impede the movement of through traffic, causing congestion and excessive emissions. Reasons for this behavior are: (a) inadequate knowledge of options; (b) advantages that outweigh waiting time; and (c) constrained parking supply.
2. Traffic Regulations and Enforcement	If a curb lane is being used as reservoir, for whatever reasons, the lane should be signed and enforced for no parking so that cars queuing for entry are not forced out into a travel lane. In cases where queues are notorious for blocking intersections, enforcement is required to maintain flow of cross-traffic.
3. Clear Signage	Clear directions to entrances and exits should be posted. Location of alternate entrances and exits could be noted, particularly if choices can be made to avoid queues.

(after 20 minutes) presumably to try elsewhere. This cruising is difficult, if not impossible to quantify, and is caused by a constrained parking supply. "Cruising" can also be a result of inadequate knowledge, as in the case of cars circling Downtown streets, searching for lots or garages with vacancies.

F. Summary

Four parking-related phenomena were linked to excessive emissions, summarized in Table 8. The major casual factors for each of the four were discussed and supported by observation and data. The following section will recommend feasible actions which would alleviate excessive idling, describe how these actions could be implemented, and estimate how this would effect localized air quality.

Table 8

SUMMARY OF RELATIONSHIP BETWEEN OPERATING CHARACTERISTICS OF PARKING FACILITIES AND AIR QUALITY CONCERNS

AIR QUALITY CONCERNS

Delay Entering +	Delay Exiting +	External Delay +	Cruising for Parking =	Excessive Emissions
# of Portals Peak arrival volumes	# of Portals Peak departure volumes	Motorist chooses to queue	Insufficient parking supply	
Type of transaction	Type of transaction	Inadequate knowledge of parking options	Inadequate knowledge of parking options	
Internal back-ups	Eveness of fee	Traffic regulations/enforcement		
External traffic interference	Traffic on street of egress	Clear signage		
Pedestrian volumes across curbcut	Pedestrian volumes across curbcut			
Internal layout	Internal layout			

VI. RECOMMENDATIONS FOR IMPROVEMENTS

Double lines of cars waiting to enter facilities, queuing through intersections and around corners, and the intersection "lock" which sometimes occur are the evidence of inefficient parking operations which can be seen any weekday in Downtown Boston. Most parking facilities operate with a minimum of queueing but even one particularly poorly operated facility can play havoc with traffic in the area, causing far-reaching system wide impacts. We have examined the characteristics of parking facilities operation and design which contribute to inefficient or effective processing of vehicles. The next step in this analysis is to answer the following questions:

- How can the operation of existing facilities be modified so as to reduce congestion?
- How can the city or other interested authority influence the design of new facilities so that queuing and congestion are minimized?

A. Air Quality Impacts of Specific Operating Improvements

This discussion will relate the findings of Chapter V to three ways (discussed on pages 8-9) in which air quality improvements can be effectuated: increasing the speed of entering/exiting cars, reducing idling time, and reducing delays to general traffic. However, only those characteristics of garage or lot operation that can be easily modified will be addressed here. Following from this discussion, a case study will be presented, estimating the possible air quality improvements resulting from hypothetical changes in operation. The next section will deal with the establishment of regulations and/or standards which can be instituted to guide the future construction and operation of parking facilities.

1. Modification to Existing Operations

Low-cost changes to existing parking operations were sought as a way of improving current congested conditions. Several actions which would improve operations, reduce congestion and excessive emissions are suggested in Table 9.

The air quality benefits arising from these improvements would vary, according to the severity of existing conditions and the unique characteristics of each situation. Generally speaking, opening additional entrances and exits during peak periods would offer the most air quality improvement, and secondly, moving gates further into facilities thus lengthening reservoir space, would have the next greatest benefits. At several facilities which experience long queues waiting for gates to open, enforcement of "no-standing" prohibitions would result in improvements in local air quality, particularly between 7 A.M - 9:30 A.M.

2. Implementation of Operational Modifications

Normally, the establishment of the operating policy of a parking facility is in accordance with a private operator's view of how to maximize profits. The City's regulation of parking, as reviewed in Section III.A, does not really address operating policy, but is almost entirely concerned with design and construction of the physical facility. However, observation made by others, as well as those found in this report, of the congestion and queuing - in terms of excessive emissions, delays to emergency vehicles, over-expenditure of gasoline and time, noise, danger to pedestrians, and general unpleasantness - leads to the conclusion that these modifications should be implemented. However, while these above listed costs are borne by the public at-large, the costs of these improvements would be paid for by the operator/owner. Therefore, an owner/operator must be induced to change the operating policy at his/her facility when it is not clear how they would benefit from the expenditure of funds.

a. Implementation Under Present Circumstances

Enforcement of "No Standing" in front of facilities would have tremendous benefits in some cases, and effort on the part of the private operator would not be required. The City would have to decide to enforce "No Standing", at the risk of angering many motorists, and also chasing them away only to increase VMT's expended through "cruising". However, over the long run, a policy of prohibiting queuing, particularly when it occurs to the extent of causing interference with traffic flow, may cause the behavior to become extinct, particularly if tagging of offenders is done.

Table 9

Measures to Improve Air Quality through Minor Modifications

I. Increasing Speeds of Entering/Exiting Cars through:	
1. Increasing Number of Open Gates	One additional entrance or exit has the potential for a capacity increase of 40 - 600 vehicles per hour. If volume remains constant but processing capacity increases, v/c ratio drops and speed increases by an amount which is dependent on the specific situation. This measure is relevant not only for the planning of new facilities, but as a guideline for the hours of operation and number of gates open in existing facilities. If queueing continually interferes with general traffic on city streets when all entrances are not open, the City should be able to induce an operator to alleviate the congestion by opening an additional gate.
2. Reducing Pedestrian/ Entering Vehicle Conflict	This impact can be mitigated by increasing the length of the reservoir between the sidewalk and gate to accommodate 3 vehicles. During constant queue conditions, a longer reservoir serves to displace delay further upstream, allowing the three cars stored prior to gate to proceed through, while those trailing in queue are held up by pedestrian flows. The interrupted vehicles can then increase their speed to rejoin cars moving through gate. Delay to total queue is less than when gate is closer to sidewalk and gate remains empty while all cars in queue are held up by pedestrian flows.
3. Internal Signage	Clear directional signage, particularly within garages would guide vehicles from one floor to another and prevent them from "doing the loop" around a floor.

II. Reducing Idling Through:

1. Speeding Up Transaction at Gate	A particularly time-consuming transaction can make a difference in idling of several seconds per vehicle, and over the course of the peak period the accumulation of these excessive emissions can be substantial. The timing of specific transaction methods are found in Tables 3 and 5.
2. Encouraging a Simple Fee Structure	Probably of minor impact and of little priority in establishment of parking rates, but could be more significant under a pay-upon-entering transaction, and result in several seconds time saving per vehicle. Automatic (computer) reading of tickets and display of fee also can save time.
3. Adequate Reservoir for Cars Exiting Facility	Similar to the situation described in mitigating pedestrian/vehicle conflicts, idling can be reduced through the provision of adequate reservoir space which allows cars to wait while attempting to join stream of traffic, without impeding the flow of vehicles through the gate. Adequate reservoir space is based on transaction time at gate and flow characteristics of street of egress.
4. Adequate Reservoir for Jockeying Cars in Valet Operations	Overcrowding in valet lots result in insufficient space for jockeying of vehicles, and entering vehicles may have to idle on-street or off-street until jockeying maneuvers are completed.

III. Reduce On-Street Delays Through:

1. Traffic Regulation	On-street parking regulations can keep curb lanes open for parking facility approaches. "No Standing" should be posted. A "No Standing" prohibition could also be used to chase away cars queueing at entrances which are closed.

2. Traffic Enforcement

If intersections are continually subject to blockage because of queueing vehicles, then police presence may be required to maintain cross movements.

Also, police could enforce "No Standing" prohibition at gates which are closed.

b. Creation of Incentive and Enforcement

For modifications that must be done by the operator/owner, perhaps it may be necessary to create a "standard of operation" to which operators must adhere. This standard would provide that all parking facilities must operate in a fashion which does not impose excessive costs upon others, e.g., cause long queues and produce traffic congestion on city streets. If it is determined that the facility is in violation of this provision, the operator would be ordered or persuaded to change his/her mode of operation or face penalties. Two major questions arise from this recommendation - where would this provision be embodied, and which authority would administer and enforce it?

One logical authority to enforce and make determinations regarding parking is the APCC. This provision could be added to its criteria, which apply to commercial facilities only. However, their authority extends only to new facilities that require approval for freeze permits or exemptions, or those requiring annual permit renewals (lots established after 1975). A major change in APCC's responsibilities and powers would need to be legislated in order to have jurisdiction over "grandfathered" facilities.

B. Case Study of Operating Improvements at Winthrop Square

One intent of this report is to point out the extent of congestion caused by parking facilities and to stimulate discussion about the need for this type of standard, enforcement options, or any other inducements for improved parking facility operation.

To illustrate what effect a standard of operation might have on existing parking facilities, a case study of one large garage located in Downtown Boston was performed.

1. Existing Operations

The Winthrop Square garage was selected as subject of a case study because it represents a "worst case" in terms of operation.

The garage is located on the edge of the Financial/South Station districts, as shown in Figure 6. One entrance and exit are located on both Federal Street and Devonshire Street (facing Winthrop Square). The traffic directions and signal locations are noted on the figure.

The garage is responsible for entering queues which extend along Federal Street, blocking the High Street intersection, impeding flow in both directions on High Street. Sometimes the congestion is so severe that it backs up onto Surface Artery. Long entering queues also can be found on Devonshire Street, from the gate back around the Summer Street intersection. The queues on Devonshire impede through-traffic on Devonshire, but do not generally interfere with Summer Street traffic.

The demand for this garage is exceedingly high. In large part, these excessive queues are a result of an unusual parking policy. Winthrop Square is a city-owned facility, privately operated under the terms of a

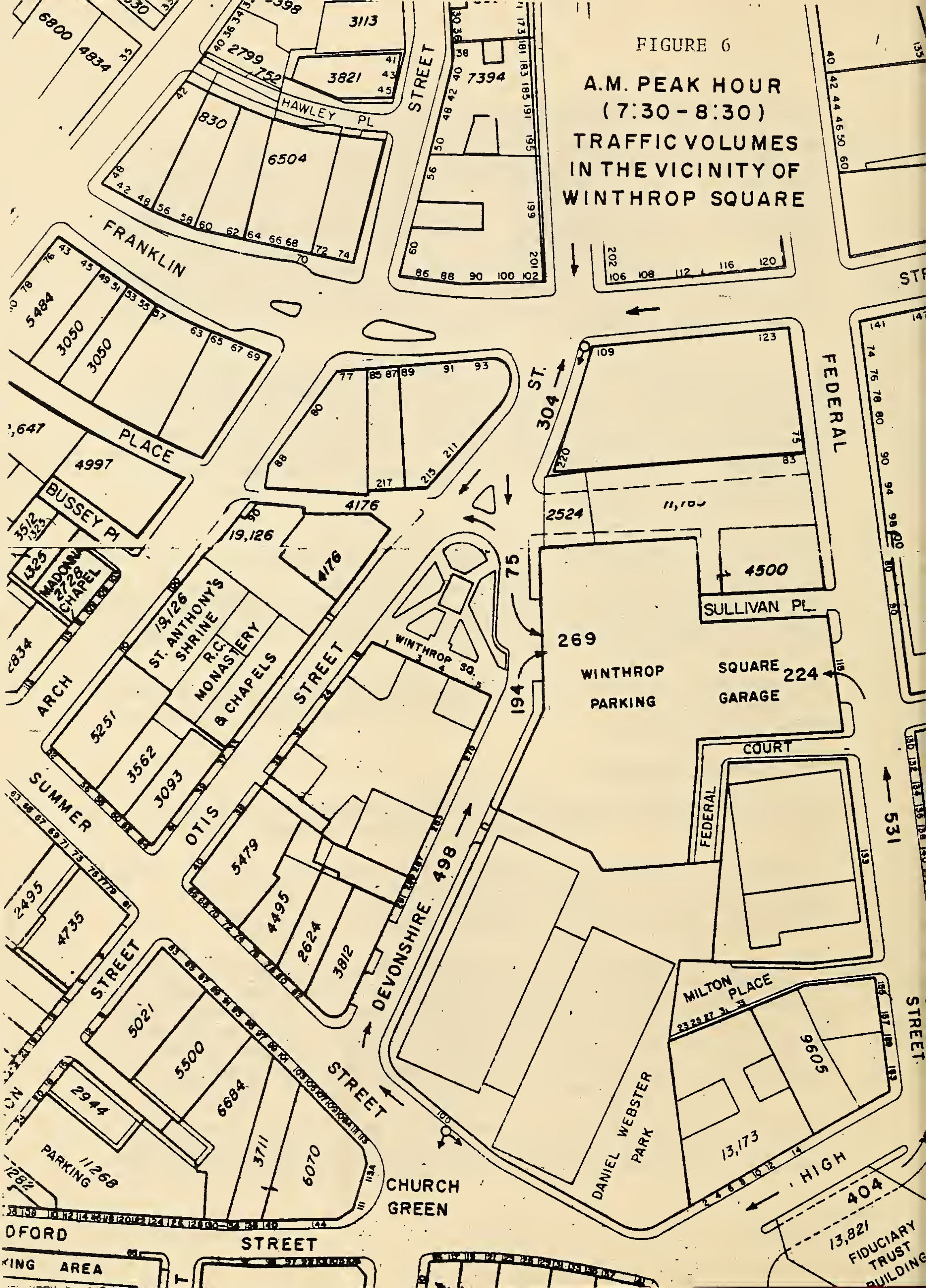


FIGURE 6

A.M. PEAK HOUR (7:30 - 8:30) TRAFFIC VOLUMES IN THE VICINITY OF WINTHROP SQUARE long-term lease. It is priced cheaply at all times relative to neighboring facilities, but also features a lower rate which is in effect after 8:00 A.M. Since the Federal Street entrance does not open until 8:00 A.M., queues form outside the garage waiting for the doors to open and the reduced prices to go into effect. Queues comprised of upwards of 36 cars were observed before 8:00 A.M, with some cars even triple-parked.

The Devonshire Street entrance is open 24 hours. Queues form before 8:00 A.M. due to the high demand relative to gate capacity. Although Devonshire is a one-way street towards Franklin along the block on which the garage is sited, there is a contraflow storage for cars coming the other way on Devonshire and waiting to enter the garage (see Figure 6). Queues form in both directions, emanating from the gate towards Summer and towards Franklin.

Queues form even after the garage is filled, due to another unusual operating strategy. Cars are self-parked within the garage, and keys are left in the vehicle. Attendants are kept busy reparking cars three or four deep, eliminating aisles. When there is no more room for self-parkers to enter, the "full" sign goes up. In the meanwhile, the attendants continue to repark cars, similar to a valet type of operation. When some additional space is created, the "full" sign is removed and several cars enter. The sign is then replaced, while the maneuvering within the garage continues, and cars continue to queue outside.

Therefore, excessive queueing at this garage results from:

- an insufficient number of entrances open during the morning peak period; and

- an operating policy which encourages queuing.

2. Effects of Modifications to Operations

Extensive data was gathered in order to measure length of queues, time in queues, travel speed, and arrivals in order to describe existing conditions and to predict how air quality may improve through implementation of some recommendations. (See Tables in Appendix).

After data collection, it became clear that the conventional manually calculated CO models would not be sensitive enough to discern changes. First, the modifications proposed here are quite microscale, and the models do not incorporate all the variables discussed here. Secondly, the peaking is so pronounced that 8-hour emission levels would not be appropriate.

FWHA's CALINE 3[17] predictive model was recommended and run for this study by Tom Wholley at the EPA. Not included in this exercise was the contribution made to CO arising from delays to external traffic, so the model underestimates the magnitude of possible improvements.

Ambient CO levels were assumed to be constant. Two model runs were made:

(1) base case CO emissions generated by existing garage traffic.

(2) projected garage generated CO emissions with the following operational changes:

- opening of Federal Street gate at 7:00 A.M. without evening surcharge.
- enforcement of "No Standing" on Devonshire Street.

Five CO receptors were sited in the model, three along Devonshire Street and two on Federal Street. (See Figure 7).

Opening the Federal Street entrance at 7:00 A.M. would have the effect of halving queues on Devonshire Street before 8:00 A.M. and reduce the queues that form on Federal Street, prior to the gate's opening. More specific impacts are detailed in Table 10. The changes in garage-generated CO levels at the five receptors arising from this proposed action are shown in Table 11, varying with wind direction.

When the wind is blowing from the south or east (90°, 135°, 180°) the CO emitted from queues along Federal and Devonshire Streets is carried back towards the receptor sites. Since those wind directions produce the worst CO "hot spots", the proposed modifications offer the greatest improvement under such conditions.

For example, across the street from the Devonshire Street entrance (Receptor 2), peak-hour CO levels are projected to decrease from 9.3 parts per million (ppm), to 2.3 when the wind is coming from the south. This is a significant reduction and is illustrative of the magnitude of improvements that could occur from this recommendation.

The second proposed modification is to eliminate the excessive queuing on Devonshire Street. In order to get some idea of its extent, every five minutes a different car in the queue was timed, starting from arrival in the queue until it passed through the gate. The times in queue are shown in the Tables found in the Appendix.

After 8:15, delays in processing incoming cars begin. Waiting time gets progressively longer as more cars are parked and it becomes more difficult to create space. On one morning, tracking random vehicles, we found waiting time of up to 49 minutes, which was representative of many other cars in line at the same time. If the surveyors had waited longer, undoubtedly longer queue times would have been recorded.

A relatively simple solution to this situation would be to ask the operator to close the facility when first full, jockey cars around to create new spaces, and reopen the facility at a posted time, such as 11:00 A.M. A sign would discourage vehicles from waiting from 9:00-11:00, and any violators would be tagged.

The operator may not agree to that suggestion, and an alternative would be to ticket queuing cars throughout the day.

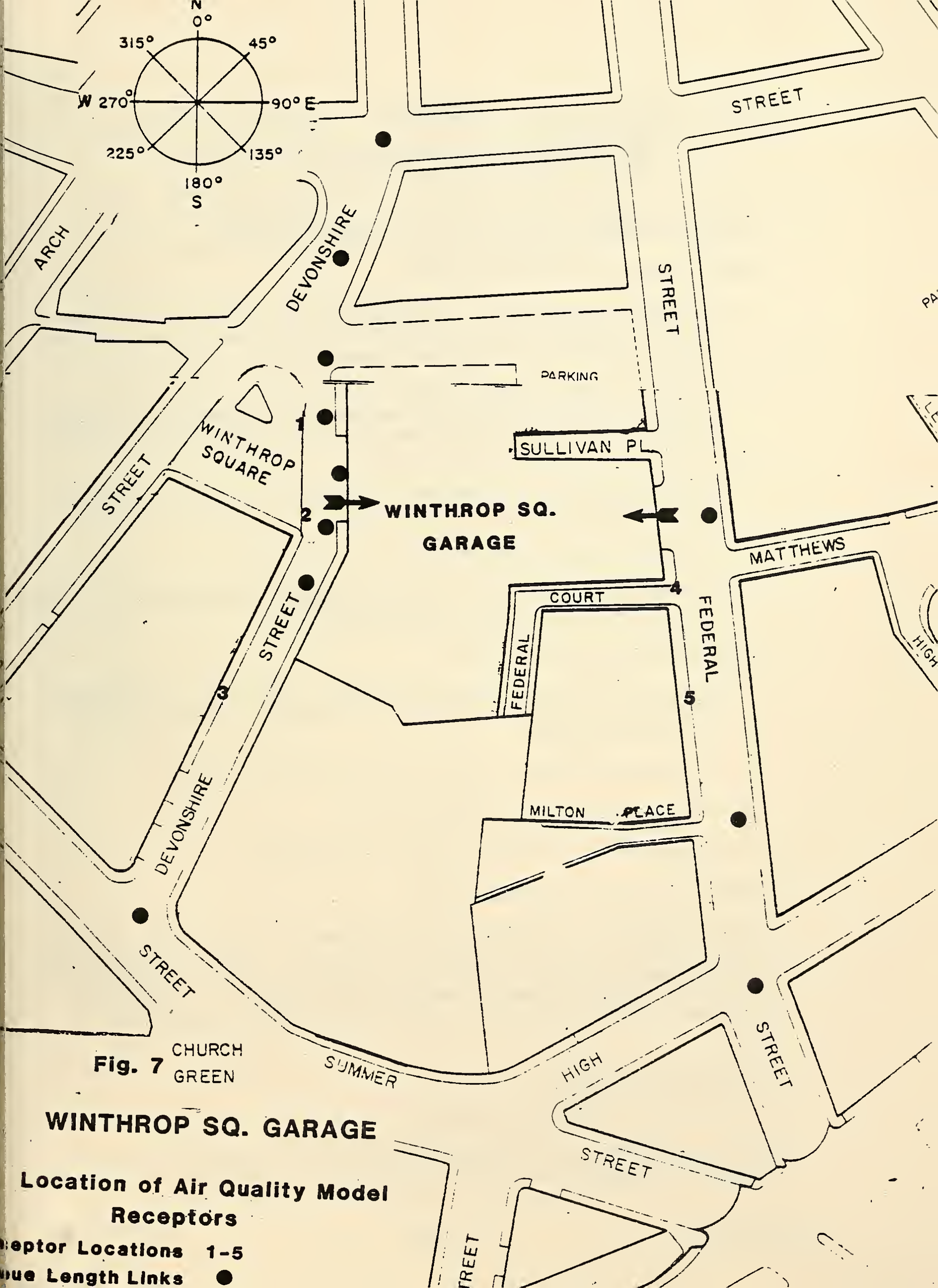


Fig. 7

WINTHROP SQ. GARAGE

Location of Air Quality Model Receptors

eptor Locations 1-5

ue Length Links ●

Table 10

Probable Impacts of Operating Modifications to Winthrop Square Garage

1. Open Federal Street Doors at 7 a.m., without Surcharge

Likely Impacts at Devonshire Street:

- Average queue lengths on Devonshire Street will be reduced from six to three between 7:30 - 7:55 a.m. since approximately half the cars will switch to the Federal Street entrance.
- The queue lengths after 7:55 a.m. will be considerably shorter since it is likely that arrivals peak between 7:55-8:15 a.m. to take advantage of the 8:00 lower rate, and many would presumably shift to earlier times, using either gate.
- Total average queue length from 7:30-8:30 a.m. would be reduced from 8 to 5 on Devonshire Street.
- Average speed of approach would not be affected.
- Average time in queue would be approximately 50 seconds (10 seconds per vehicle, 80% moving time and 20% idle.

Likely Impacts at Federal Street:

- The idling of vehicles waiting for door to open would be eliminated. Now, the average waiting time of cars between 7:30-8:00 a.m. is 10 minutes per car.
- Average queue length would be reduced from 10.6 to 6.
- Time to gate would average 60 seconds.
- Average approach speed would not be affected.

General Impacts: (Not Modelled)

Traffic congestion on Federal and High Streets will be reduced, as the queueing before 8:00 a.m. blocks the intersection, and on some occasions causes delays extending to the Surface Artery. Assume an average delay of 5 seconds per vehicle between 7:30-8:30 a.m. for High Street and Federal Street traffic (531 vehicles) is eliminated through this action.

2. No Standing Prohibition

Likely Impacts at Devonshire Street:

After the garage closes in order for attendants to valet park so as to squeeze more cars in, queues form waiting for the garage to let a trickle of additional vehicles in. The average weighted idle time of vehicles between 8:20-9:30 a.m. is almost 16 minutes for 68 vehicles. This queueing and idling would be virtually eliminated.

On Federal Street, up to 36 cars queue before 8:00 a.m. idling for an average of 10 minutes. This would drop to 5 minutes.

Travel speed would not change significantly.

Table 11

Peak-Hour Garage Generated Carbon Monoxide in Parts Per Million

(levels after improvements in parenthesis)

Wind Direction	Receptor Locations 1	2	3	4	5
0°	.3 (.3)	5.3 (5.3)	.3 (.2)	2.1(2.2)	5.8(6.5)
45°	1.0 (.4)	11.5(11.4)	2.1(1.1)	7.3(7.5)	7.9(7.5)
90°	5.9(4.5)	9.6 (9.2)	1.2 (.8)	7.3(7.3)	7.3(2.7)
135°	8.1(8.3)	9.6 (4.3)	.2 (.2)	8.8(8.2)	8.2(1.2)
180°	3.4(1.9)	9.3 (2.3)	.3 (.3)	2.7(1.7)	1.6 (.6)
225°	0 (0)	1.1 (.1)	0 (0)	.1(.1)	.1 (.1)
270°	0 (0)	0 (0)	0 (0)	.8(.4)	.1 (0)
315°	0 (0)	.6 (.6)	0 (0)	.2(.2)	.6 (5)

(Background levels not included)

In Table 12 the effect of this proposed action upon the three receptors located along Devonshire Street is shown. The projected peak-hour decreases in garage-generated CO levels is quite significant, and demonstrates the deleterious effect that excessive idling has on local air quality. At receptor Location 2, CO can be reduced as much as from 11.5 to 1.0 ppm during the peak hour, if the wind is coming from the 45° direction. Other wind directions also would produce decreases in CO, particularly at receptors 1 and 2, located closest to the entrance.

3. Conclusion

If recommendations as those described above were implemented, dramatic decreases in CO could occur at downtown receptor sites. Even though the garage chosen for this case study represents a worst case, this exercise may understate the range of improvements since garage-generated delays to through traffic were not estimated.

Opening additional gates and limiting queuing are two actions which probably produce the greatest reduction in CO. Both of these actions primarily reduce idling, which makes a significant contribution to CO hot spots. Idling concentrates emissions, whereas cars moving, even at slow speeds, disperse emissions. Implementing some of the other suggested techniques would increase travel speeds, and thus reduce CO levels, although less dramatically then does elimination of idling. Some of the garages mentioned in this report could avail themselves of these suggested improvements. For example, Dock Square Garage could move its entry gates further into the facility to shorten queue lengths, and minimize interference with Surface Artery. UnderCommon should raise its rates to be in keeping with other facilities, keep two gates operating throughout the time it is accepting cars during the morning peak, and then not reopen until 11:00. Post Office Square is very similar in operation to Winthrop Square, and the same air quality improvements would be expected through the recommended operating modifications.

The City-owned mechanical garages are all slated for redevelopment, and will cease to be a problem within the next two to four years.

Overall, of the 88 garages in Boston Proper, representing 35,000 parking spaces, perhaps half of them could benefit by implementing some of these recommended actions. A relatively small number produce as severe conditions as does Winthrop Square, so it would be expected that the average decrease in CO would be smaller.

Implementation of these recommendations could realize an average peak-hour decrease of 3 ppm to 4 ppm CO under worst case wind conditions at forty to fifty parking lots and garages in Boston Proper. Not only would there be a significant alleviation of CO "hot spot" conditions, but 8-hour averages also would reflect the peak-hour reductions.

It should also be noted that reductions in hydrocarbons (HC) would result from increasing average travel speeds. At 5 mph, 17 grams/mile of HC are emitted, compared to 7 grams at 15 mph. HC is a regional problem, rather than concentrated in "hot spots", and improvements such as those suggested above to increase travel speeds would help to alleviate HC pollution in the Metropolitan area.

Table 12

Peak-Hour Garage Generated Carbon Monoxide in Parts Per Million

(levels after improvements in parenthesis)

Wind Angle	Receptors Locations 1	2	3
0°	.3 (.3)	5.3 (.7)	.3 (.0)
45°	1.0 (.4)	11.5(1.0)	2.1(.4)
90°	5.9(.9)	9.6 (1.6)	1.2 (1.2)
135°	8.1(1.3)	9.6 (1.2)	.2 (.2)
180°	3.4(.4)	9.3 (1.0)	.3 (.3)
225°	0 (0)	1.1 (.1)	0 (0)
270°	0 (0)	0 (0)	0 (0)
315°	0 (0)	.6 (.1)	0 (0)

(Background levels not included)

C. Guidelines and Standards for Future Construction

The guidelines and standards presented in Section III, pertaining to parking facility design do not adequately safeguard the City's interest in regards to minimizing congestion and excessive air pollution. The list of design characteristics found in Table 13 is offered as a suggestion of the elements that should be considered and examined during conceptual and design stages of a proposed parking facility.

The numbers of entrances and exits is the most important indicator of processing capacity. Guidelines proposed here suggested that there be approximately one entrance for every 500 spaces, and one exit for every 400 spaces, appropriate for the typical fee and ticket transaction.

Minimizing queuing on street by entering vehicles can be accomplished by lengthening the reservoir area between the street and the gate. Depending on the characteristics of the street of egress, an adequate number of spaces should be provided for between the gate and the street so that difficulties in entering the flow of traffic do not cause back ups interfering with gate operation. As a rule of thumb, a typical exit transaction takes about 20-25 seconds, so the volumes and signal phasing at the upstream intersection should indicate the ease of merge.

Another factor in reducing emissions within a parking garage is an efficient layout. Signage, express exiting and comprehensible internal circulation assists in reducing delays and reducing distance travelled within a facility.

These elements are meant to serve as a point of discussion at this time; however, some of these elements might be most useful if incorporated in APCC or Zoning requirements, and others may be best used as reference during design review. All however, have a positive effect on air quality.

D SUMMARY

The City of Boston attempts to minimize vehicular congestion through a variety of methods, including the administration of a Freeze on the growth of commercial parking spaces, installation or removal of traffic signals, implementing street directional changes, and regulation of curb parking. The City also has powers of review for most proposed large developments through curb cut permits, zoning variances, and for parking specifically through the Air Pollution Control Commission.

Since the private operation of parking facilities in many cases causes congestion and imposes costs on the public at-large, the City should look towards establishment and enforcement of an operating standard. This standard would call for the operation of a parking facility in a manner that would not impede traffic flow or cause excessive air pollution. If an owner/operator was in violation of the standard, several mitigating measures are proposed in this report which should bring any facility up to standard.

Guidelines for future facility construction may also be useful in preventing future congestion in the vicinity of parking garages.

Table 13

1. Location of Entrances and Exits

   a. Street Orientation

      - On one-way street
      - On two-way street with median preventing left turn into and out of facility
      - On minor street
      - On street side of greatest length (maximizing distance from intersection)

   b. Portal Location

      Entrance: As far away from upstream intersection as possible.

      Exit: Downstream from entrance.

      - Both should be designed with an awareness of pedestrian routes in order to reduce conflicts between pedestrians and moving vehicles.

   c. Number of Portals

      - Entrance: 1/500 spaces
      - Exit: 1/400 spaces
      - If demand is demonstratively not subject to severe peaking, standards could be relaxed.
      - If fee transaction is anticipated to be more time-consuming (uneven fees, pay upon entrance) the portal/capacity ratio should be higher.
      - If fee transaction is quick (monthly passes, pay elsewhere and hand receipt) the portal/capacity ratio could be lower.

2. Design

   a. Entering Reservoir

      - If parking lane on street of ingress cannot be used for reservoir, the area between curb cut and gate should be able to accommodate no less than 5 vehicles per 500 capacity.
      - If pedestrian flows are particularly heavy, the reservoir should be a car length or two longer than otherwise to allow for surge that may delay gate access.

   b. Exiting Reservoir

      - Length of driveway between gate and curb cut is dependent upon traffic on street of egress. Upstream signal phasing and peak period traffic volumes past site should indicate the ease or difficulty in merging with traffic. During peak exiting times, vehicles will attempt to join stream of traffic every 20 seconds on the average. One additional reservoir space should be provided for any delays longer than 20 seconds in turning into traffic.

c. Internal Layout

- Travel through facility can be expedited through careful design of turning radii; ramp grades, one-way patterns and angled parking. Express exiting should be provided in large, multi-storied facilities, (5-6 stories) and floor bypasses should be provided so that cars travelling up through occupied levels can be routed directly to vacancies rather than having to circle the entire floor in order to proceed to the next level. Electronic signs directing patrons to vacant floors should be installed in large multi-floor facilities. Emissions savings would be based upon number of floors in facility and travel distance saved through direct connections between floors, or express exiting.

3. Operation

- Gate equipment and transaction mode should be appropriate for type of operation, and should emphasize quick ingress and egress.

FOOTNOTES

1. Transportation Element of the State Implementation Plan for The Boston Region (TESIP), Central Transportation Planning Staff, November, 1978, p.17.

2. TESIP, p.17.

3. Parking Garage Planning and Operation, The ENO Foundation for Transportation, Inc., Westport, CT, 1978, p.45.

4. The Dimensions of Parking, Urban Land Institute and National Parking Association, Washington, DC, p.61.

5. Parking Principles, special report #125, Highway Research Board, National Academy of Sciences, 1971, p.115.

6. *ibid*., p.116.

7. The Dimensions of Parking, p.62.

8. ENO, p.45.

9. Richard C. Rich and Michael Moukalian, "Design of Structures", from The Dimensions of Parking.

10. Parking Principles, p.116.

11. Richard C. Rich., *op*. *cit*.

12. Parking Principles, p.115.

13. Richard C. Rich., *op*. *cit*.

14. Jerome Gottesman, "Ventilation", from The Dimensions of Parking, p.93.

15. *ibid*., p.93.

16. The Dimensions of Parking, p.62.

17. CALINE 3 - A graphical solution procedure for estimating Carbon Monoxide (CO) concentration near roadways, December 1980, U.S. Department of Transportation, Federal Highway Administration.

APPENDIX

Variables for Air Quality Predictive Model

1. Distance from Garage entrances to Intersection:

Federal-High	350 ft.
Devonshire-Summer	360 ft.
Devonshire-Franklin	240 ft.

2. Signal Green Time - A.M. Peak Period

Federal-High	
for High, left turn onto Federal	44/100 sec.
for High, right turn onto Federal	48/100 sec.
Devonshire-Franklin, for Devonshire	32/70 sec.
Summer-Lincoln, for Summer (Devonshire)	47/100 sec.

3. 1980 A.M. Peak Traffic Volumes	7:30-8	8-8:30	8:30-9
Federal-High			
for High, left turn onto Federal	156	248	325
for High, right turn onto Federal	37	90	127
Devonshire-Franklin, contra-flow into garage only	54	41	11
Summer-Devonshire, right turn onto Devonshire	269	220	182

4. Garage Arrivals			
Federal St. entrance	0	224	55
Devonshire St.	170	119	41
TOTAL:	170	343	96

5. Peak 5 min. arrivals = 40
   7.5 sec./vehicle-entering time

6. Average Peak Period Queue Length (taken at 5 min. intervals)
   Federal St. = 10.6
   Devonshire St. = 9.0

7. Average Speed while moving in Queue
   Federal St. entrance = 3.6 mph
   Devonshire St. 2.34 mph

8. Average Time spent in Queue
   Federal St. - 117 sec. (1 min., 57 sec.)
   Devonshire St. = 523 sec. (8 min., 43 sec.)

Winthrop Square Garage

Devonshire Street Entrance

Time	# of Ins	# of Cars in Queue at beginning of Time	Total Time to Gate of last Car in Queue	Distance to Gate of last Car in Queue	Moving Time in Queue
7:30-7:34	28	5	0:54	100'	0:54
7:35-7:39	31	9	1:32	160'	1:32
7:40-7:44	32	0	-	-	
7:45-7:49	29	8	missed it	-	
7:50-7:54	21	6	0:42	120'	0:42
7:55-7:59	29	10	1:53	140'	-
8:00-8:04	33	17	2:45	360'	1:13
8:05-8:09	33	15	1:55	260'	0:50
8:10-8:14	35	10	1:48	140'	0:44
8:15-8:19	13	5	0:44	100'	0:13
8:20-8:24	4	3	4:17	50'	0:23
8:25-8:29	1	8	car left queue	140'	-
8:30-8:34	4	10	6:41	230'	0:57
8:35-8:39	16	13	timing before car		
8:40-8:44	0	8	19:00	140'	insignificant
8:45-8:49	0	9	-		
8:50-8:54	4	9	22:00		insignificant
8:55-8:59	6	8	17:00		insignificant
9:00-9:04		8	left queue		
9:05-9:09		9	49:00		insignificant
9:10-9:14		12			
9:15-9:19		11			
9:20-9:24		8			
9:25-9:29		6			
9:30-9:34		11			
9:35-9:39		11			
9:40-9:44		11			
9:45-9:49		10			
9:50		11			

Av. = 9.0

Peak hour
arrivals (ins)

7:30-8:00 = 170
8:00-8:30 = 119

TOTAL = 289

Devonshire Street Entrance

Starting Time		Total Time in Queue (seconds)	Moving Time	Idle Time	% Moving Time	Speed* (mph)
See # - previous sheet						
7:30	1	54	54	0	100%	1.26
7:35	2	92	92	0	100%	1.19
7:40	3	0	0	0	0	0
7:50	4	42	42	0	100%	1.95
7:55	5	113	113	-	100%	.84
8:00	6	205	73	132	36%	3.36
8:05	7	115	50	65	43%	3.55
8:10	8	108	44	64	41%	2.17
8:15	9	44	13	31	30%	5.24
8:20	10	257	23	234	9%	1.48
8:25	11	car left				
8:30	12	401	57	344	14%	2.39
8:40	13	1140	insignificant		10%	-
8:50	14	1320	insignificant		10%	-
8:55	15	1020	insignificant		10%	-
9:05	16	2940	insignificant		5%	-

Average = 523 sec.

Average = 2.34
Speed in qu

*Conversion factor: $\frac{\text{ft.}}{\text{sec.}} = \frac{.682\ \text{m}}{\text{hr.}}$

Federal Street Entrance

Time	# of Ins	# of Cars in Queue at beginning of Time	Total Time to Gate of last Car in Queue	Distance to Gate of last Car in Queue	Moving Time in Queue
7:55-7:59	0	30*	6:42	360'	1:28
8:00-8:04	45	20**	2:38	340	1:08
8:05-8:09	44	16	2:18	330	1:06
8:10-8:14	34	17	2:16	350	0:57
8:15-8:19	37	17	2:22	350	1:06
8:20-8:24	31	12	2:03	300	0:51
8:25-8:29	33	15	2:19	320	0:51
8:30-8:34	9	2	0:14	220	0:07
8:35-8:39	27	17	3:28	380	0:55
8:40-8:44	6	0	0	-	-
8:45-8:49	8	0	0	-	-
8:50-8:54	1	1	0:45	-	0:02
8:55-8:59	4	2	0:15	-	0:15
9:00		0			

*More than 30 cars were in the queue; but it extended around the corner to High Street and could not be seen from our vantage point. We estimate 36 cars were in the queue at 8:00.

**This interval count actually began at 8:01:50, rather than 8:00.

Peak hour arrivals (ins) =
8-8:30 = 224
8:30-9 = 55
TOTAL = 279

Federal Street Entrance

Starting Time	Total Time in Queue (seconds)	Moving Time	Idle Time	% Moving Time	Speed* (mph)
7:55-7:59	402	88	314	22%	2.79
8:00-8:04	158	68	90	43%	3.41
8:05-8:09	138	66	72	48%	3.41
8:10-8:14	136	57	79	42%	4.19
8:15-8:19	142	66	76	46%	3.62
8:20-8:24	123	51	72	41%	4.01
8:25-8:29	139	51	88	37%	4.28
8:30-8:34	14	7	7	50%	1.95
8:35-8:39	208	55	153	26%	4.71
8:40-8:44	0	-	-	-	-
8:45-8:49	0	-	-	-	-
8:50-8:54	45	2	43	4%	-
8:55-8:59	15	15	0	100%	-

Average Speed = 3.6 mph
in queue

Conversion factor:

$$\frac{\text{ft.}}{\text{sec.}} = .682 \frac{\text{miles}}{\text{hr.}}$$